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Space Systems Division

LRB

LIQUID ROCKET BOOSTER STUDY

ADDENDUM TO FINAL REPORT

AUGUST 31, 1990

CONTRACT NO. NAS8-37137
(MOD 10)

NATIONAL AERONAUTICS & SPACE ADMINISTRATION
MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

90-9550-9

(NASA-CR-184127) LIQUID ROCKET BOOSTER STUDY ADDENDUM Final Report (General Dynamics Corp.) 59 p CSCL 21H
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G3/20 0008039

LRB STUDY ORGANIZATION

LRB

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LRB LAUNCH VEHICLE CONCEPTS

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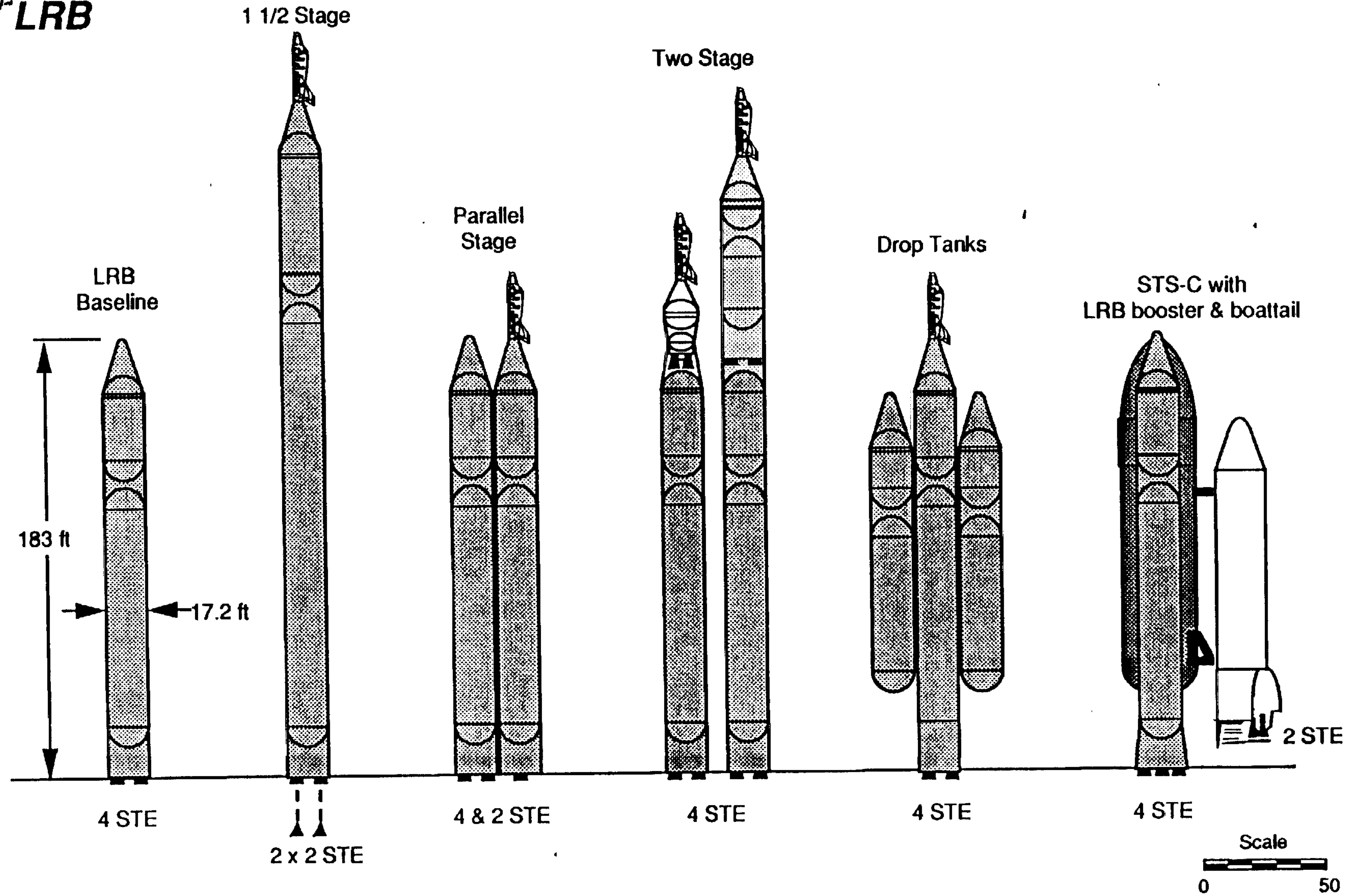

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CONCEPT SUMMARY
LO_2/LH_2 PUMP-FED WITH STE (JAN '90 DESIGN)

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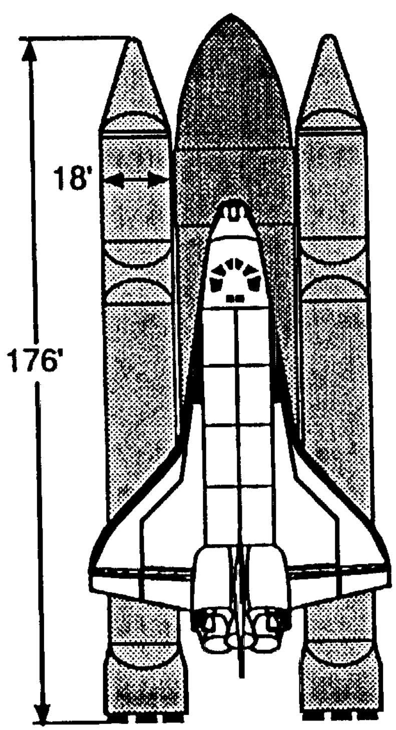

SELECTION RATIONALE
- CLEAN EXHAUST PRODUCTS; NON-TOXIC
- PROPELLANT COMMONALITY WITH STS LAUNCH
- SUBSTANTIAL EXPERIENCE BASE
- LIGHTEST GROSS WEIGHT IN CLASS
- NEW "LOW COST" ENGINE (STE)
- PREFERRED FOR ALTERNATE APPLICATIONS (ALS, STANDALONE)
- EXPENDABLE

PROGRAMMATIC DATA (1987 $)*

- TOTAL NON-RECURRING COST: $3,673 M
- AVERAGE UNIT COST, FOR 140 FLIGHTS: $35.2M
- LIFE-CYCLE COST, FOR 10 YEARS: $14,466M

ENGINE THRUST	LRB ASCENT PROPELLANT WEIGHT	SHUTTLE GLOW	THRUST/ WEIGHT @L/O (NOMINAL)	ISP
510,475 (sl) 549,492 (v)	1,359,305	3,564,861	1.46	386 (sl) 415 (v)

* EXCLUDES CONTRACTOR FEE, GOVERNMENT SUPPORT AND CONTINGENCY

LRB DESIGN IMPROVEMENTS

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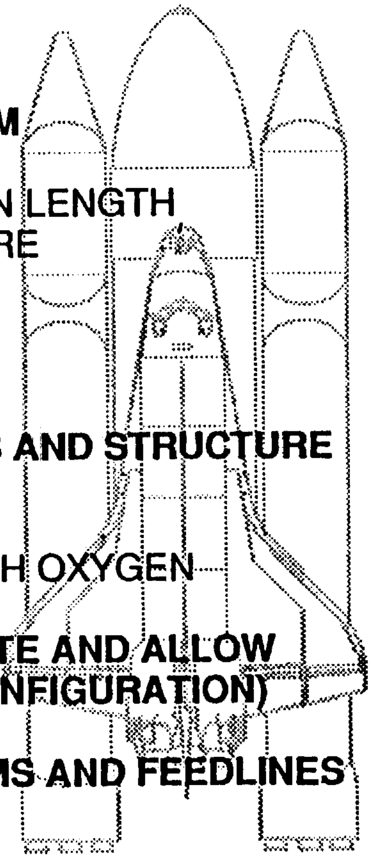

- **RESOLVED FORWARD ATTACH POINT PROBLEM**
  - SIZE WAS 17.2 FT IN DIAMETER BY 183 FT IN LENGTH
  - ATTACH POINT IS IN INTERTANK STRUCTURE
- **ADOPTED STE AS BASELINE ENGINE**
  - 20:1 EXPANSION RATIO
- **ADOPTED 2090 AL-LI AS MATERIAL FOR TANKS AND STRUCTURE**
  - 7% WEIGHT SAVINGS
  - RECENT NASA ACCEPTANCE FOR USE WITH OXYGEN
- **REDESIGNED AFT SKIRT TO ACCOMMODATE STE AND ALLOW FOR CLOSE MOUNTING OF LRB (PARALLEL CONFIGURATION)**
- **REFINED WEIGHT ESTIMATES FOR SUBSYSTEMS AND FEEDLINES**

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BASELINE LRB (APRIL '90 DESIGN)

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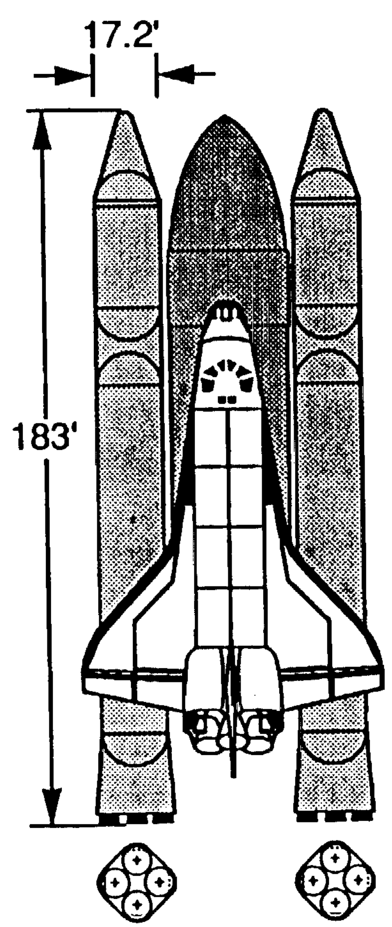

Design Goals:

Safe abort at any point in trajectory
ATO Capability with single LRB engine out at lift off
Minimum impacts to current STS

Weights (lbs):

Payload	70,500
LRB Dry Weight	113,039
LRB Inert Weight	123,141
LRB Ascent Propellent	655,640
LRB GLOW	788,781
STS/LRB GLOW	3,521,797

LRB Propulsion:

Number of engines per LRB	4
Engine type	STE
Area Ratio	20:1
Vacuum Thrust (lbs)	558,542
Sea Level Thrust (lbs)	514,232
Vacuum Isp (sec)	413
Sea Level Isp (sec)	380

LIQUID ROCKET BOOSTER BASELINE WITH STE ENGINES

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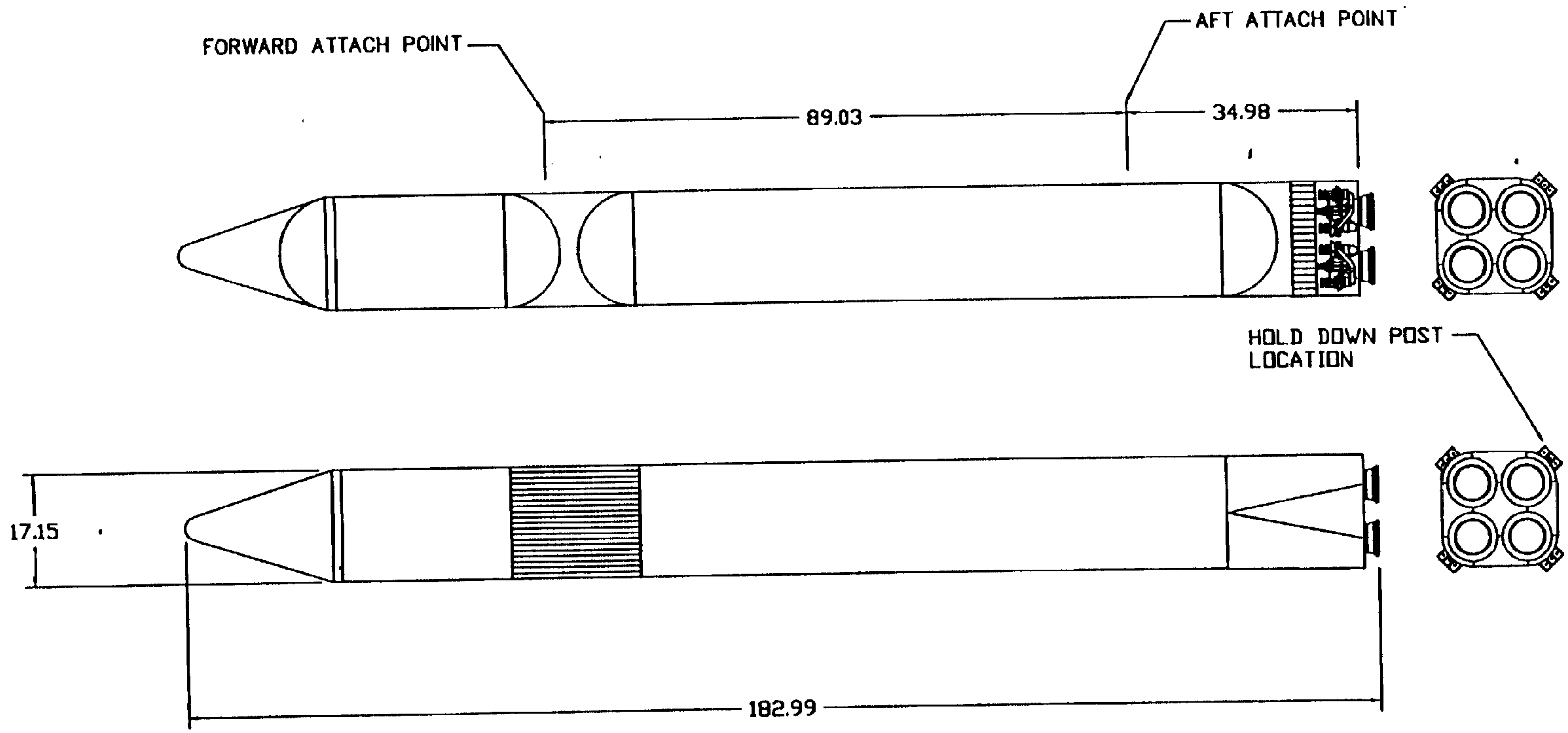

ATTACH POINT SOLUTIONS

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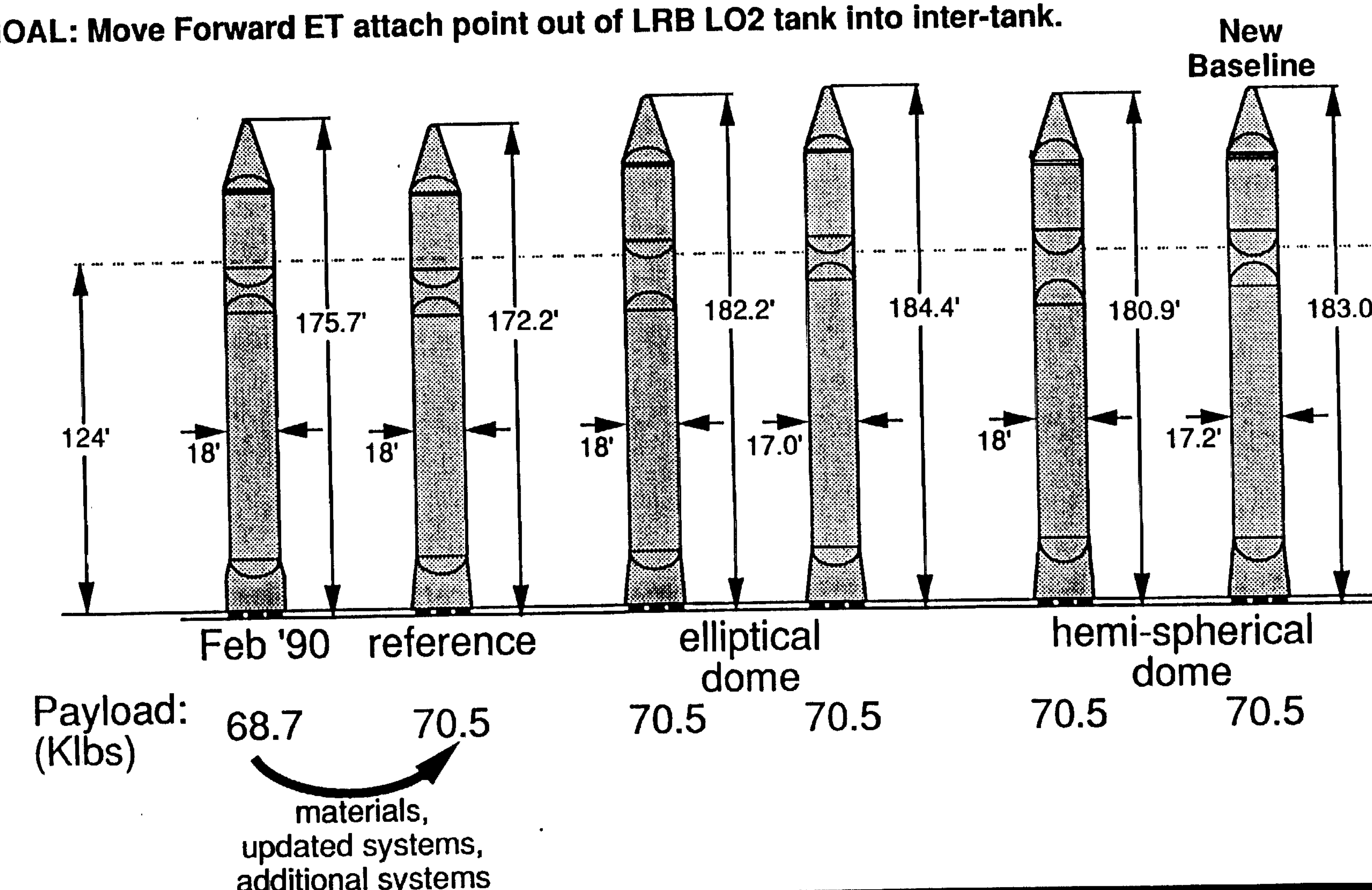
GOAL: Move Forward ET attach point out of LRB LO2 tank into inter-tank.



LRB USING STE20 vs. STE40

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Question: What are the advantages/disadvantages of modifying STEs for a STS LRB?

	STE20	STE40
Nozzle Area Ratio Payload (lbs) LRB Length (ft) LRB Diameter (ft)	20:1 70,500 183.0 17.2	40:1 62,690 182.6 16.8
Aft Skirt:	Square with rounded corners, permits side-by-side LRB placement	Flared, requires large attach beam for side-by-side LRB placement
Engine:	Requires STE to have two nozzle designs but can use common combustion chamber and turbo pumps	Single STE design

ABORT CAPABILITY

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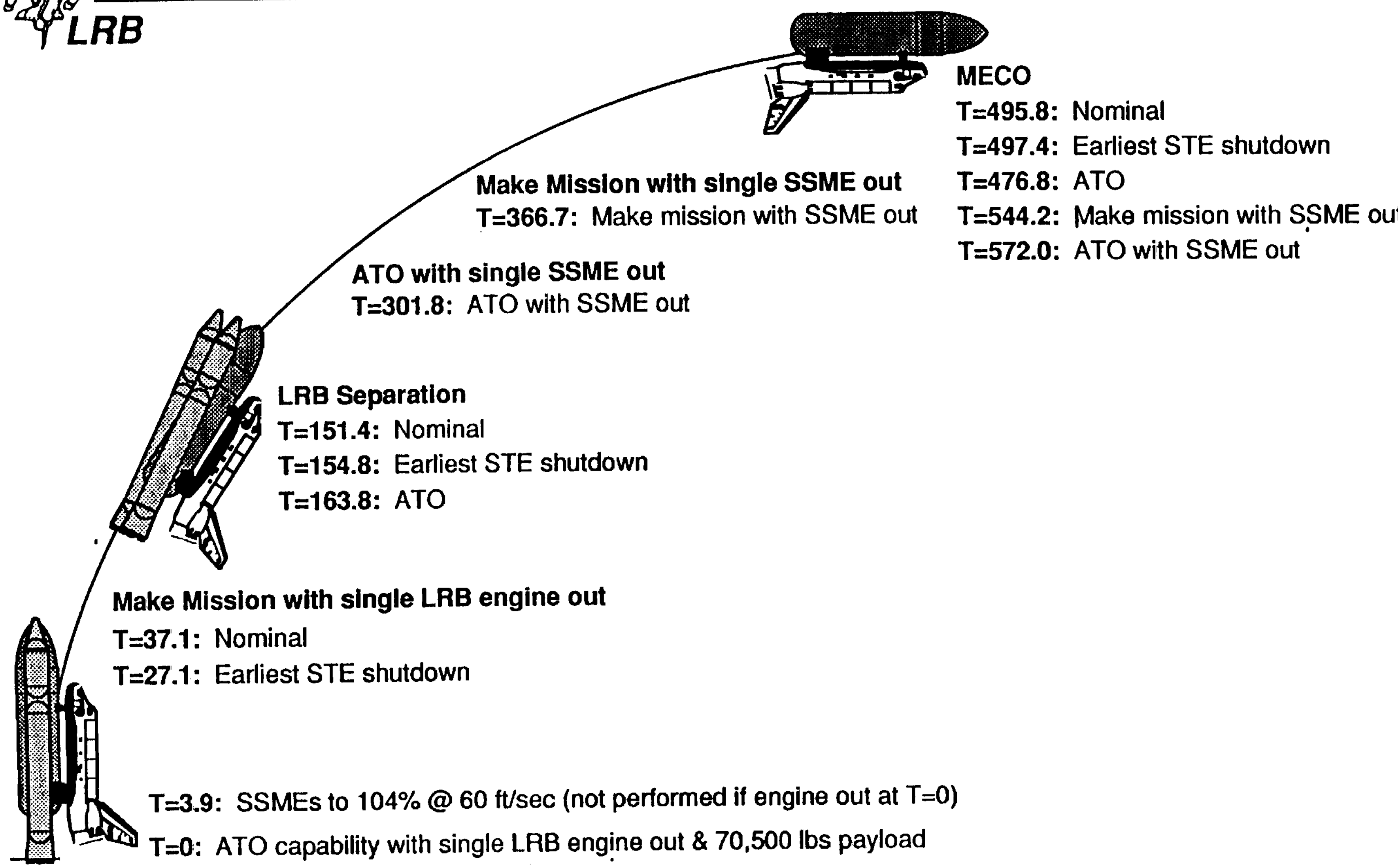


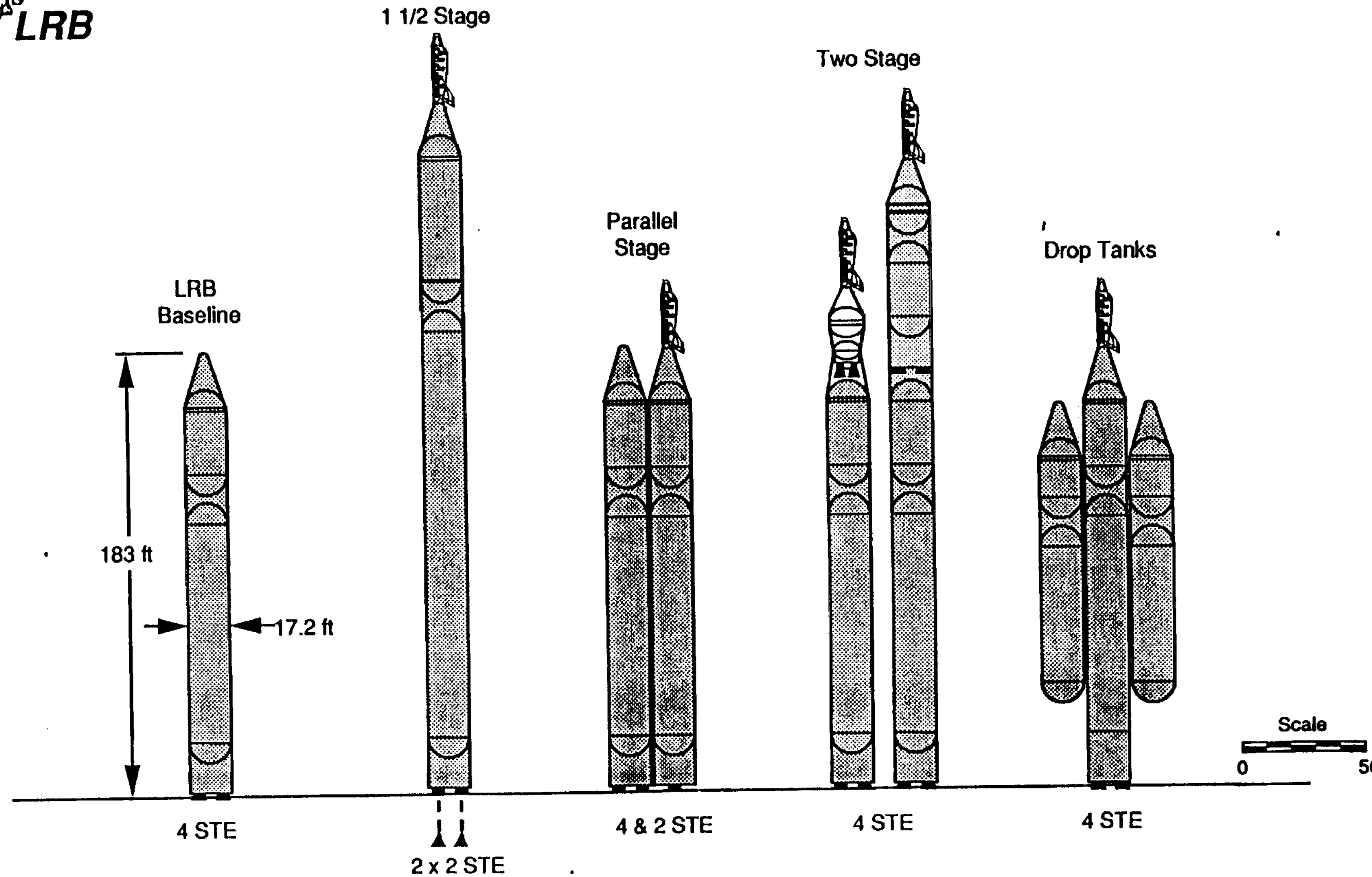
Lift-off: SSMEs at 100%, LRB STEs at 100%

LRB DERIVED PLS LAUNCH VEHICLE STUDY ACTIVITIES

OBJECTIVE

- Evaluate Options of Developing a PLS Launch Vehicle (LV)
  - Utilize LRB
  - Optimize from LRB
- Determine the Best Commonality and Cost Effective Concept

LRB LAUNCH VEHICLE CONCEPTS



LV FOR PLS STUDY PLAN

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APPROACH

- Utilize the LaRc 10 Man PLS as Basic Concept

- Conduct Trade Analyses on four LV from LRB concepts:

  1) 1 1/2 Stages
  2) Parallel
  3) 2 Stages (2nd Stg = Centaur & LRB)
  4) Drop Tanks

- Evaluate for PLS Insertion Orbits, nmi, of:

  A) 50 X 100
  B) 39 X 217 (SSF Transfer Orbit)
  C) 220 X 220 (2 Stage only)

PLS LV
OPTIONS & COMMONALITIES CONSIDERATIONS

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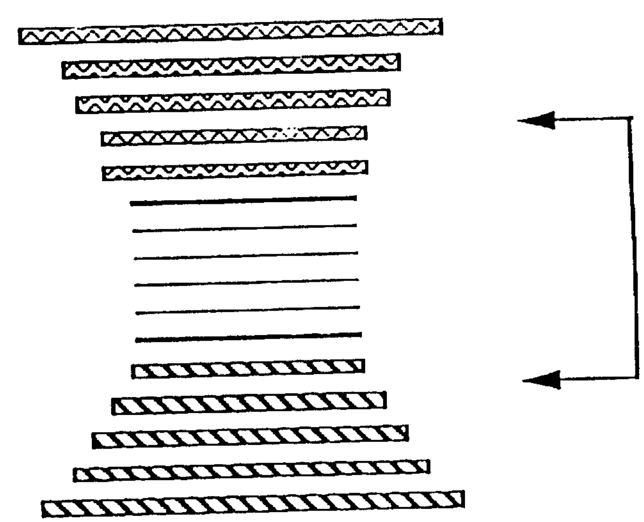
LV OPTIONS: • 1/2 Stages •Parallel Stages • 2 Stages • Drop Tanks

LEVEL OF COMMONALITY - LRB TO LV IMPACTS

Increases Changes In

- Tank Wall Thk
- Wp/Tank Sizes
- Structures
- STE Requirements
- KSC Impacts

Commonality - LRB to LV



Range of Best Compromise Concept

Optimized - LV from LRB

PLS LV
GROUND RULES AND CONSTRAINTS

PLS

• LaRc 10 Man Orbiter, Wt	= 22,744 lb
• Adapter (initial) W/Escape System, Wt	= 10,543
Lift Off, payload Wt	= 33,287 lb

LRB LAUNCH VEHICLES FOR PLS

- Boosters = LRB materials and STEs
- 2nd Stage Engines = RL-10 for Centaur and STE for LRB Derivative
- 2nd Stage to have Controlled Reentry from 220 X 220 NMi Orbit
- Avionics for G&N = GD Adaptive G & N Type
- Trajectory Constraints: Max q = 850 psf; Max g = 3

LaRc 10 MAN PLS

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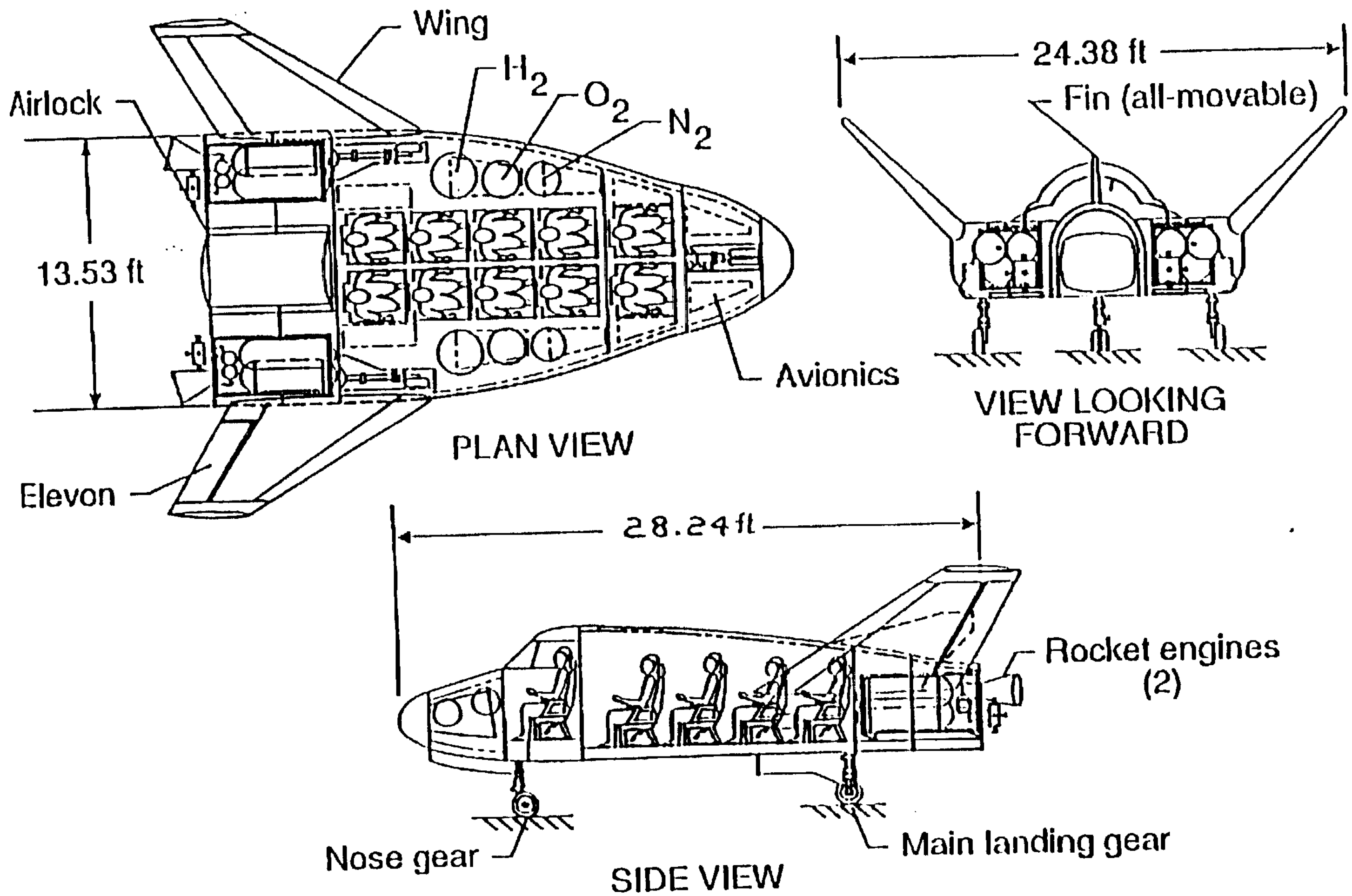

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BASELINE PROPELLANT FEED SYSTEM

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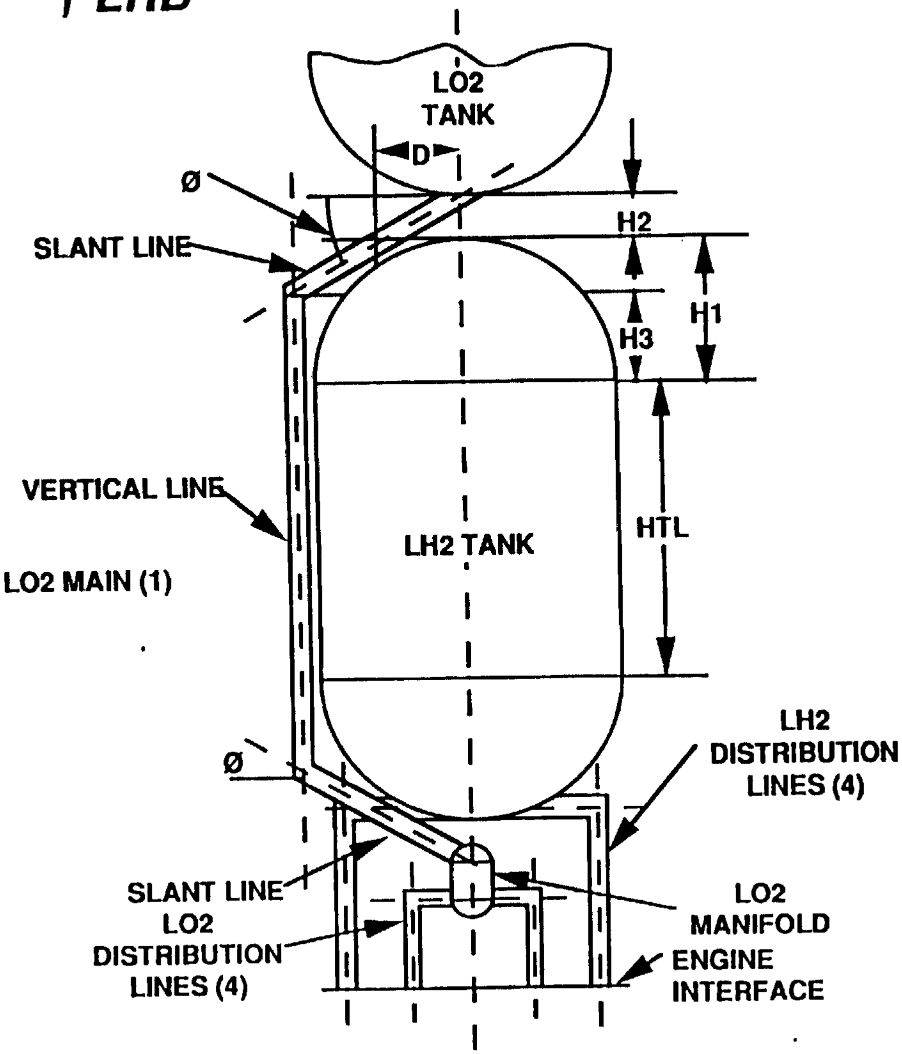

FEEDLINES	LENGTH inches	I.D. inches	WEIGHT pounds
L02			
MAIN FEED		22	
SLANT LINES			
INTERTANK	103.8		
AFT SKIRT	88.8		
VERTICAL RUN	1236.9		
MANIFOLD			123
DISTRIBUTION LINES - 4 REQD.		12	
HORIZONTAL RUN	26.4		
VERTICAL RUN	29.3		
LINE WEIGHT			1393
COMPONENTS WEIGHT			1504
FLEX JOINTS - 3		22	
FLEX JOINTS - 1		12	
GIMBAL JOINT - 1		12	
PREVALVE		12	
LO2 TOTAL WEIGHT			3020
LH2			
DISTRIBUTION LINES - 4 REQD.		12	
HORIZONTAL RUN	86.4		
VERTICAL RUN	81		
LINE WEIGHT			82
COMPONENTS WEIGHT			1000
FLEX JOINTS -1		12	
GIMBAL JOINTS -1		12	
LH2 TOTAL WEIGHT			1328
SYSTEM TOTAL WEIGHT			4348

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BASELINE PROPULSION SUPPORT SYSTEMS

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VENT SYSTEM - DUCTED TO MLP QD

LINE LENGTHS	
LO2	2114 inches
LH2	1561 inches
LINE WEIGHTS	
LO2	524 lbs
LH2	387 lbs
COMPONENT WEIGHT PER LINE	209 lbs
TOTAL WEIGHTS	
LO2	733 lbs
LH2	596 lbs
SYSTEM TOTAL	**1329 lbs**

PRESSURIZATION SYSTEM

LINE LENGTHS	
INTERNAL	73 inches
EXTERNAL	
LO2	2062 inches
LH2	1509 inches
LINE WEIGHTS	
INTERNAL	27 lbs
EXTERNAL	
LO2	143 lbs
LH2	127 lbs
TOTALS	
LO2	266 lbs
LH2	250 lbs
SYSTEM TOTAL	**515 lbs**

PNEUMATIC SYSTEM

ESTIMATED FROM ORBITER

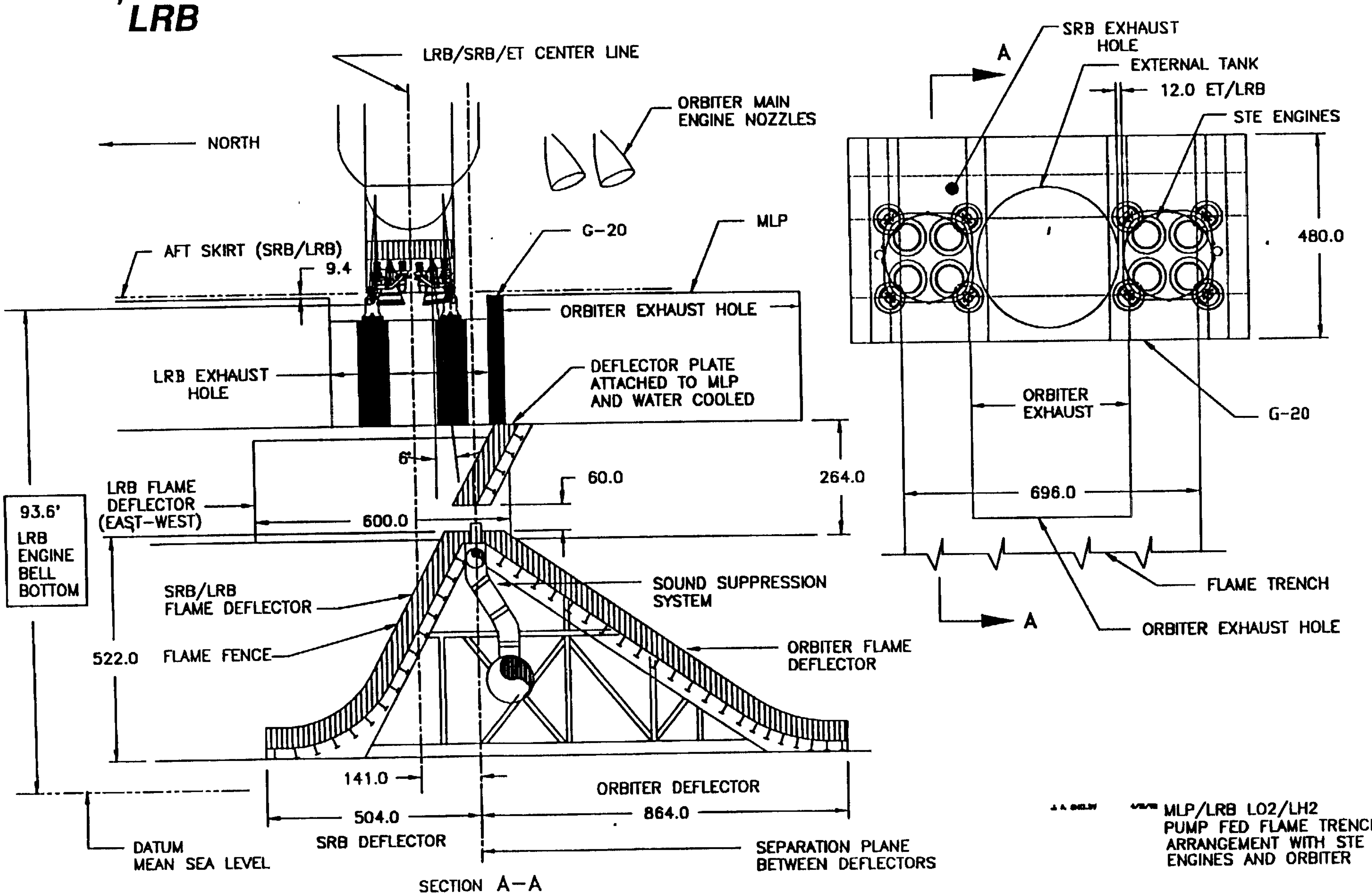
TOTAL WEIGHT **591 lbs**

FILL AND DRAIN SYSTEM

SAME AS ORBITER

LH2	261 lbs
LO2	242 lbs
TOTAL	**503 lbs**

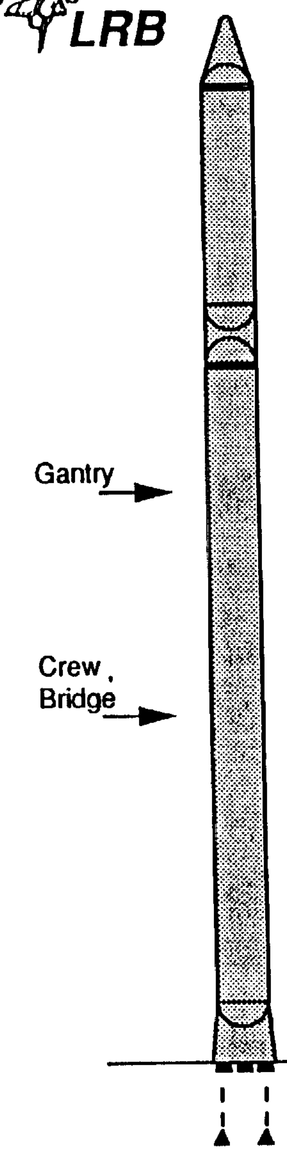
LRB

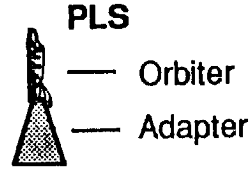


MLP/LRB LO2/LH2 PUMP FED FLAME TRENCH ARRANGEMENT WITH STE ENGINES AND ORBITER

1.5 STAGE PLS LAUNCH VEHICLE

LRB





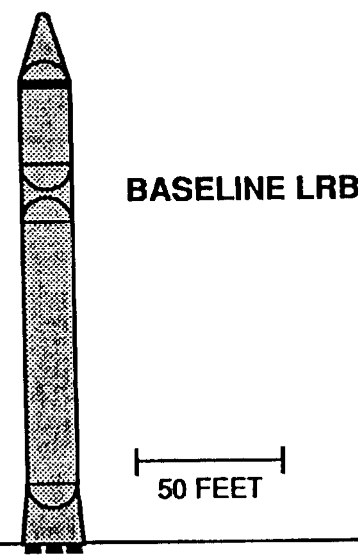
LRB/PLS 1.5 STAGE VEHICLE

- Would not reach destination orbit of 50x100nm.
- Ascent Trajectory Simulation Aborted.

Performance Parameters at Termination of Simulation:

GLOW	=	1,780 Klbs
H2 Weight	=	225 Klbs
O2 Weight	=	1,348 Klbs
Qty STEs	=	4, drop 2
LV Length	=	356.7 ft.
LV Diameter	=	17.4 ft.
PL to 50x100	=	0

1.5 LRB MFrac	=	0.88
Atlas MFrac	=	~0.95



1.5 STAGE LRB IS INCAPABLE OF DELIVERING PLS TO LEO DUE TO LRB/STS WEIGHT REQUIREMENTS

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PARALLEL PLS LAUNCH VEHICLE

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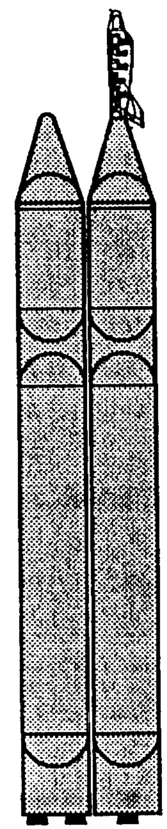
- Minimum Modifications to STS - LRB = [shaded]
- Simulations performed with 1 Core engine out

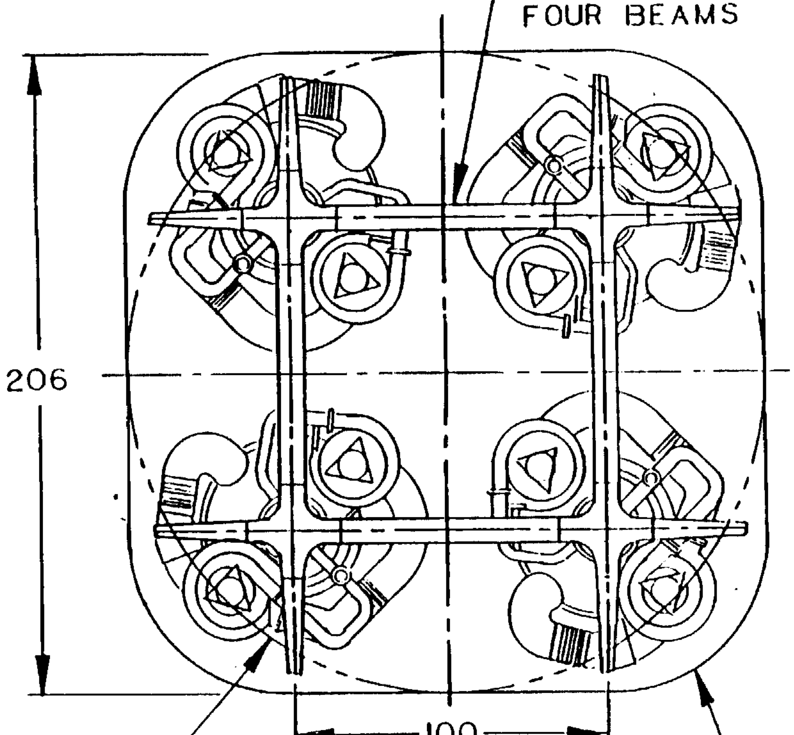


	50 x 100 nm		SSF Transfer	
Vehicle Parameters	LRB min mod	Optimized from LRB	LRB min mod	Optimized from LRB
Payload (Klbs)	53.5	33.3	49.4	33.3
Booster Inert Weight (Klbs)	123.1	112.6	123.1	114.7
Ascent Propellent (Klbs)	665.6	531.5	665.6	558.0
Upper Stage Inert Weight* (Klbs)	95.8	88.8	95.8	90.9
Ascent Propellent (Klbs)	665.6	531.5	665.6	558.0
GLOW (Klbs)	1,603.7	1,297.7	1,599.6	1,355.0
Vehicle Length (ft)	211	185	211	190
Vehicle Diamter (ft)	17.15	17.15	17.15	17.15
Qty Booster Engines (STE-20)	4	4	4	4
Lowest Throttle Setting	75%	75%	75%	75%
Qty Core Engines (STE-20)	2	2	2	2
Lowest Throttle Setting	75%	75%	75%	75%

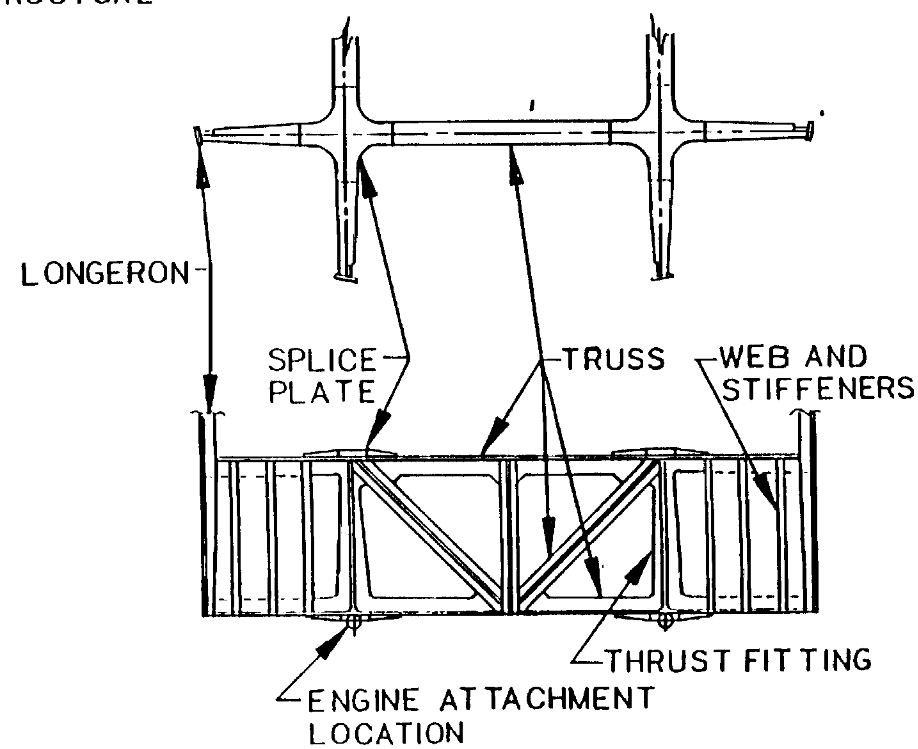
*Upper stage inert weight includes: dry weight + residuals + FPR

LRB SQUARE SKIRT
4 - STE ENGINE CONFIGURATION

LRB



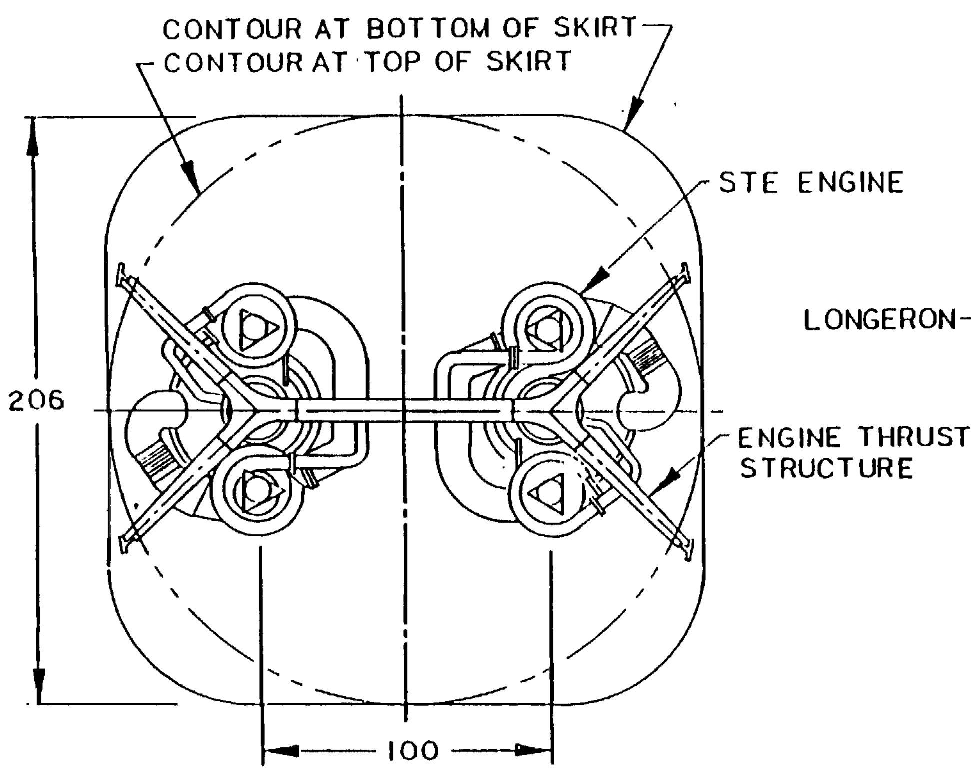
VIEW LOOKING DOWN (AFT) AT ENGINES



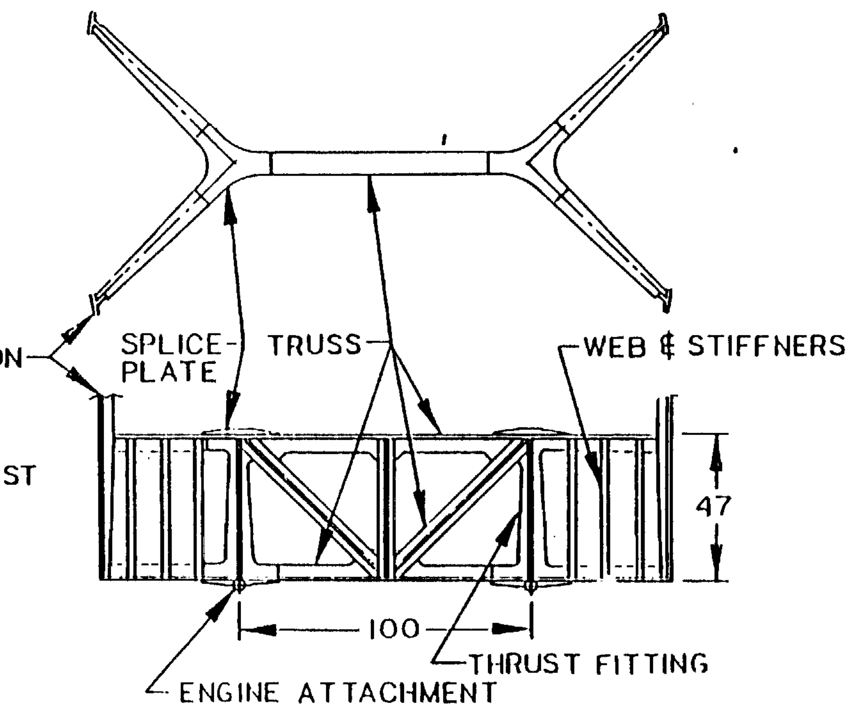
ENGINE THRUST STRUCTURE
FOUR ENGINE CONFIGURATION

LRB SQUARE SKIRT
2 - STE ENGINE CONFIGURATION

LRB



VIEW LOOKING DOWN (AFT) AT ENGINES



ENGINE THRUST STRUCTURE
TWO ENGINE CONFIGURATION

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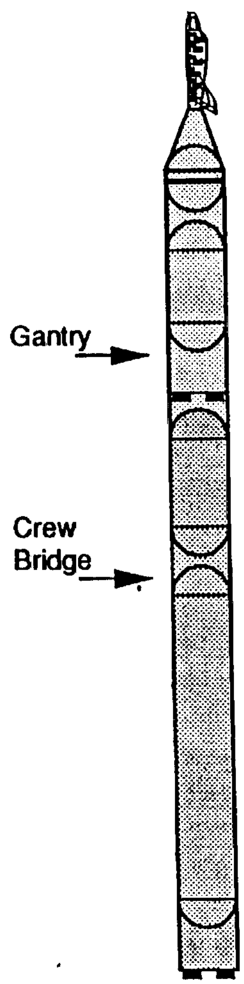
2 STAGE PLS LAUNCH VEHICLE
2-STE "LRB" UPPER STAGE

LRB



- Payload Delivered = 33,287 lbs; PLS Orbiter and Adapter
- Minimum Modifications to STS - LRB = (shaded)

Vehicle Parameters	50 x 100 nm LRB min mod	50 x 100 nm Optimized from LRB	SSF Transfer LRB min mod	SSF Transfer Optimized from LRB	220 x 220 LRB min mod	220 x 220 Optimized from LRB
Booster Inert Weight (Klbs)	111.8	99.8	111.8	102.9	111.8	113.7
Ascent Propellent (Klbs)	665.6	592.5	665.6	632.9	665.6	645.9
Upper Stage Inert Weight* (Klbs)	60.0	62.6	62.3	62.7	71.3	75.1
Ascent Propellent (Klbs)	223.2	256.2	252.3	257.5	285.4	330.3
GLOW (Klbs)	1,099.6	1,044.3	1,131.0	1,089.3	1,173.2	1,198.3
Vehicle Length (ft)	286	277	292	285	300	305
Vehicle Diamter (ft)	17.15	17.15	17.15	17.15	17.15	17.15
Qty Booster Engines (STE-20)	4	3	4	3	4	4
Lowest Throttle Setting	59%	75%	63%	75%	75%	75%
Qty Upper Stage Engines (STE-20)	2	2	2	2	2	2
Lowest Throttle Setting	25%	26%	26%	26%	28%	30%

*Upper stage inert weight includes: dry weight + residuals + FPR + $\boxed{\text{restart + deorbit}}$ 220x220 only

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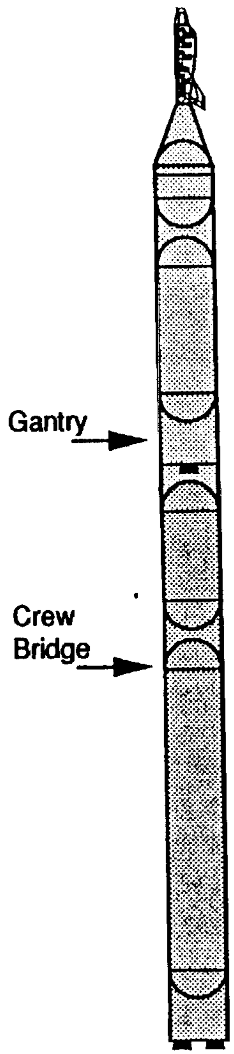
2 STAGE PLS LAUNCH VEHICLE
1-STE "LRB" UPPER STAGE

LRB

- **Payload Delivered = 33,287 lbs; PLS Orbiter and Adapter**
- **Minimum Modifications to STS - LRB =** (shaded)



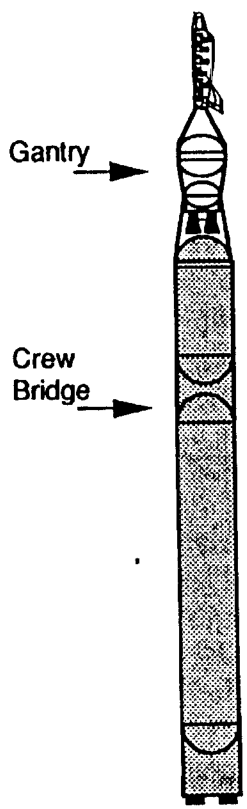
	50 x 100 nm		SSF Transfer		220 x 220	
Vehicle Parameters	LRB min mod	Optimized from LRB	LRB min mod	Optimized from LRB	LRB min mod	Optimized from LRB
Booster Inert Weight (Klbs)	111.8	95.6	111.8	97.6	111.8	113.7
Ascent Propellent (Klbs)	665.6	539.1	665.6	564.7	665.6	645.9
Upper Stage Inert Weight* (Klbs)	62.7	50.6	65.9	50.8	75.9	75.1
Ascent Propellent (Klbs)	242.7	212.3	282.1	215.0	326.2	330.3
GLOW (Klbs)	1,121.8	930.9	1,164.4	961.4	1,218.5	1,198.3
Vehicle Length (ft)	308	258	316	264	326	285
Vehicle Diamter (ft)	17.15	17.15	17.15	17.15	17.15	17.15
Qty Booster Engines (STE-20)	4	3	4	3	4	4
Lowest Throttle Setting	62%	75%	67%	75%	75%	75%
Qty Upper Stage Engines (STE-20)	1	1	1	1	1	1
Lowest Throttle Setting	52%	45%	53%	45%	59%	30%

*Upper stage inert weight includes: dry weight + residuals + FPR + restart + deorbit
220x220 only

2 STAGE PLS LAUNCH VEHICLE
CENTAUR UPPER STAGE

LRB

- Payload Delivered = 33,287 lbs; PLS Orbiter and Adapter
- Minimum Modifications to STS - LRB = [shaded]
- Centaur sized for Payload Requirements (man-rated)



	50 x 100 nm		SSF Transfer		220 x 220	
Vehicle Parameters	LRB min mod	Optimized from LRB	LRB min mod	Optimized from LRB	LRB min mod	Optimized from LRB
Booster Inert Weight (Klbs)	111.8	95.1	111.8	96.4	111.8	101.3
Ascent Propellent (Klbs)	665.6	533.4	665.6	548.9	665.6	611.7
Upper Stage Inert Weight* (Klbs)	8.3	9.3	8.4	9.3	10.1	10.1
Ascent Propellent (Klbs)	36.2	58.2	38.7	57.4	47.2	48.4
GLOW (Klbs)	**861.0**	**729.3**	**863.6**	**745.2**	**873.7**	**804.8**
Vehicle Length (ft)	**235**	**212**	**236**	**215**	**239**	**225**
Vehicle Diamter (ft)	17.15	17.15	17.15	17.15	17.15	17.15
Qty Booster Engines (STE-20)	4	3	4	3	4	3
Lowest Throttle Setting	**26%**	**35%**	**26%**	**35%**	**27%**	**35%**
Qty Upper Stage Engines (RL10-A4)	2	2	2	2	2	2
Lowest Throttle Setting	100%	100%	100%	100%	100%	100%

*Upper stage inert weight includes: dry weight + residuals + FPR + restart + deorbit (220x220 only)

2 DROP TANK LRB PIPING SKETCH

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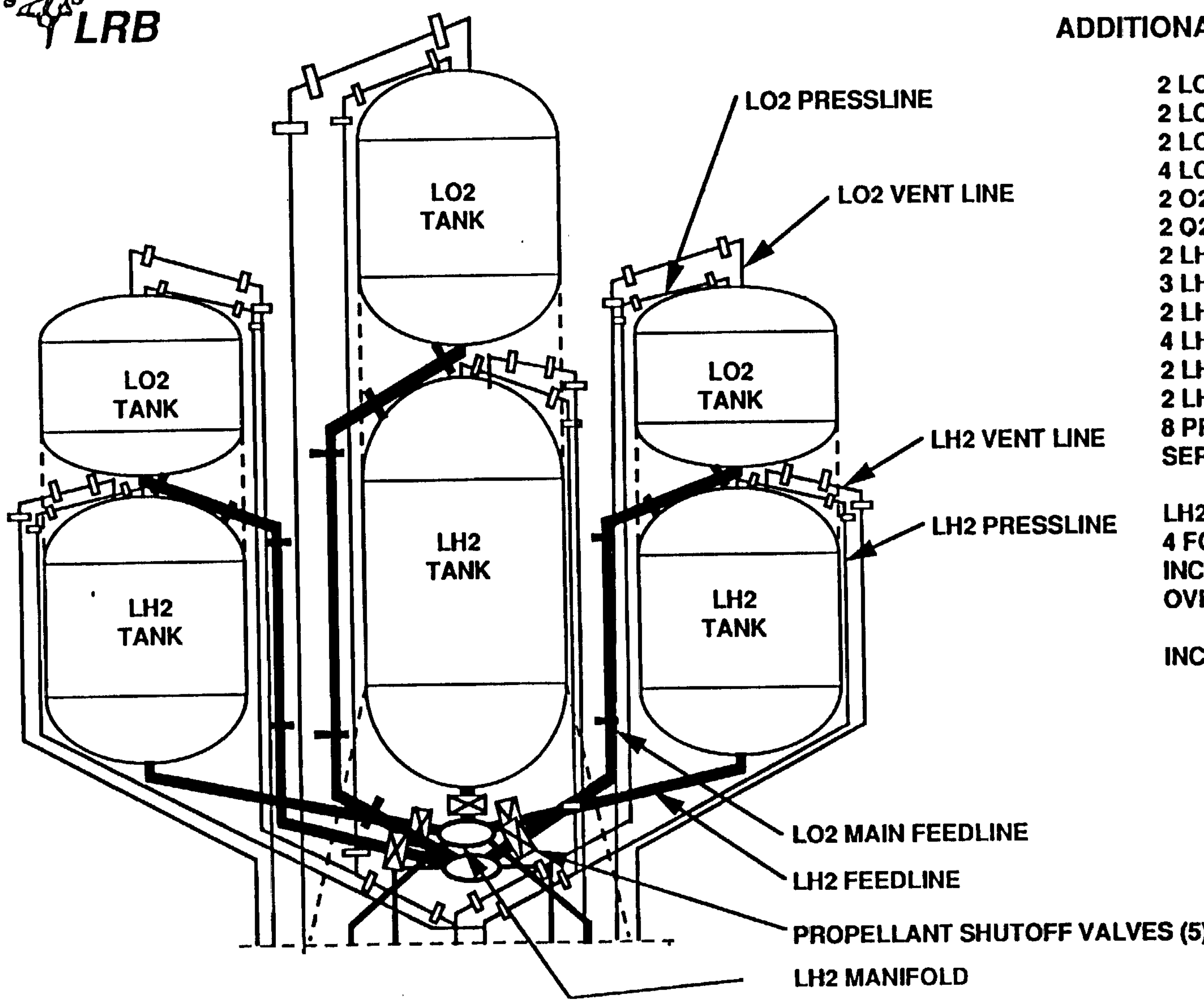

ADDITIONAL COMPONENTS IN CORE

2 LO2 FEEDLINE QD's
2 LO2 FEEDLINE SOV's
2 LO2 FEEDLINE CV's
4 LO2 GIMBAL JOINTS
2 O2 PRESSLINE QD's
2 O2 PRESSLINE SOV's
2 LH2 FEEDLINE QD's
3 LH2 FEEDLINE SOV's
2 LH2 FEEDLINE CV's
4 LH2 GIMBAL JOINTS
2 LH2 PRESSLINE QD's
2 LH2 PRESSLINE SOV's
8 PRESSLINE GIMBAL JOINTS
SEPARABLE VENT LINE SUPPORTS (4)
LH2 MANIFOLD
4 FOOT SKIRT EXTENSION
INCREASED PNUEMATIC SYSTEM
OVERSIZED FILL AND DRAIN SYSTEM
INCREASED BATTERY WEIGHT

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PLS LV
CONCEPT TECHNICAL EVALUATIONS STATUS

LRB

RATING: 1 = low; 2 = mid; 3 = high

CONCEPT	RATING	REMARKS
• 1 1/2 Stage	2	Unable to achieve orbit; Mass Fraction too low; may work if unconstrained
• Parallel	3	Offers most commonality, fits PAD tower best for man ingress/egress, STE throttling req'd within current range
• 2 Stage		
- LRB Type Upper Stage W/1 Eng	2	Greatest commonality of 2 Stg concepts, high 2nd Stage throttling req'd
- LRB Type Upper Stage W/2 Eng.	1	2 STEs on 2nd Stage too much, very high Throttling req'd
- Centaur Type Upper Stage	3	Shortest and lightest of 2 Stage concepts, high throttling req'd on 3 &4 STE Boosters, 2 STE Booster probably better option NOTE: PLS above Gantry for all 2 Stage options
• Drop Tanks	1	Plumbing too complex, no advantages over Parallel

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FINDINGS AND RECOMMENDATIONS

LRB

FINDINGS TO-DATE

CONCEPT ITEMS	ATTRIBUTES	CONCERNS
A. Parallel	- Most common to LRB - Least PAD Tower Impact - within STE throttle (75%)	- Involves 2 LRBs
B. 2 Stage W/1 Eng LRB US	- Uses LRB components	- High STE throttle (2 engine Booster will reduce) - PAD Tower Impact
C. 2 stage W/Centaur	- Shorter & lighter 2 Stage	- High STE throttle (2 engine Booster will reduce) - PAD Tower Impact
D. 1 1/2 Stage	- Simplifed Concept	-- STS Constraints Effect Wts.
E. Both 2 Stage W/2Engines & Drop Tanks	- None	- Not Practical

RECOMMENDATIONS FOR REMAINING MOD 10 EFFORTS

- Cease further work on Concepts in Item E.
- Continue further design studies on Concepts in Items A, B , C & D
  - Refine concepts with size and structures unconstrained by STS, as required
  - Provide cost analyses

LRB BOATTAIL FOR SHUTTLE-C APPLICATION

LRB

OBJECTIVE:

Develop a Conceptual Design To Determine The Feasibility Of Utilizing The LRB Boattail (Aft Skirt) For Shuttle-C Application

ASSUMPTIONS & GROUNDRULES
CONCEPT DESIGN-LRB BOATTAIL FOR SHUTTLE-C

LRB

- Maximized use of STS-C boattail subsystems shall be made
- No impact to ET, ET Aft Attach Provisions, Cargo Carrier, Flame Trench, and only minor mods to other subsystems and GSE
- The baseline STE shall be used without mods except to the nozzle expansion ratio
- The Shuttle-C LRB boattail conceptual design shall be the 2-STE configuration
- The STS 3-g load factor limit shall apply to the LRB configured Shuttle-C
- LRB boattail STEs shall have same thrust vector angle as the STS-C boattail SSMEs
- The SRBs are replaced by LRBs on Shuttle-C with an LRB Boattail

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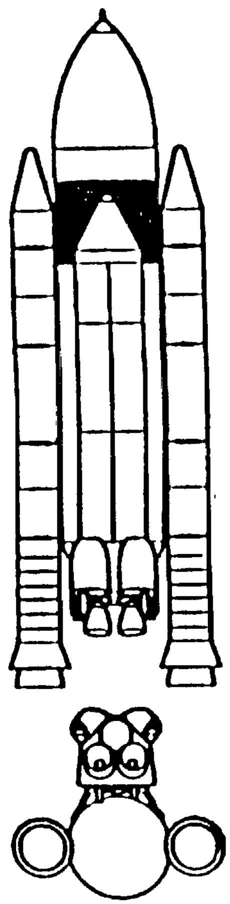
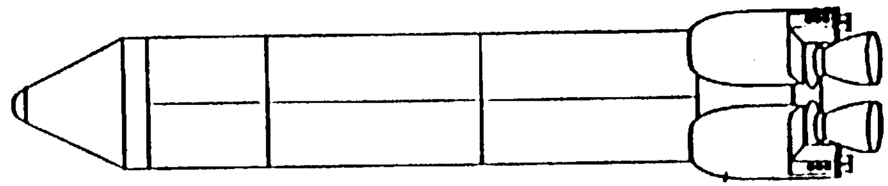
SHUTTLE-C CARGO ELEMENT (CE) SUB-ELEMENTS

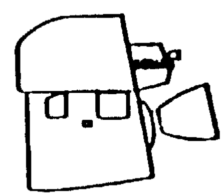
LRB



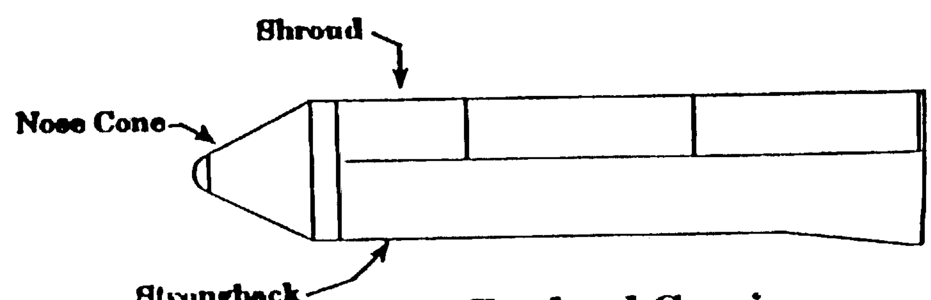
Shuttle-C (SH-C)



Cargo Element



Boattail



Payload Carrier

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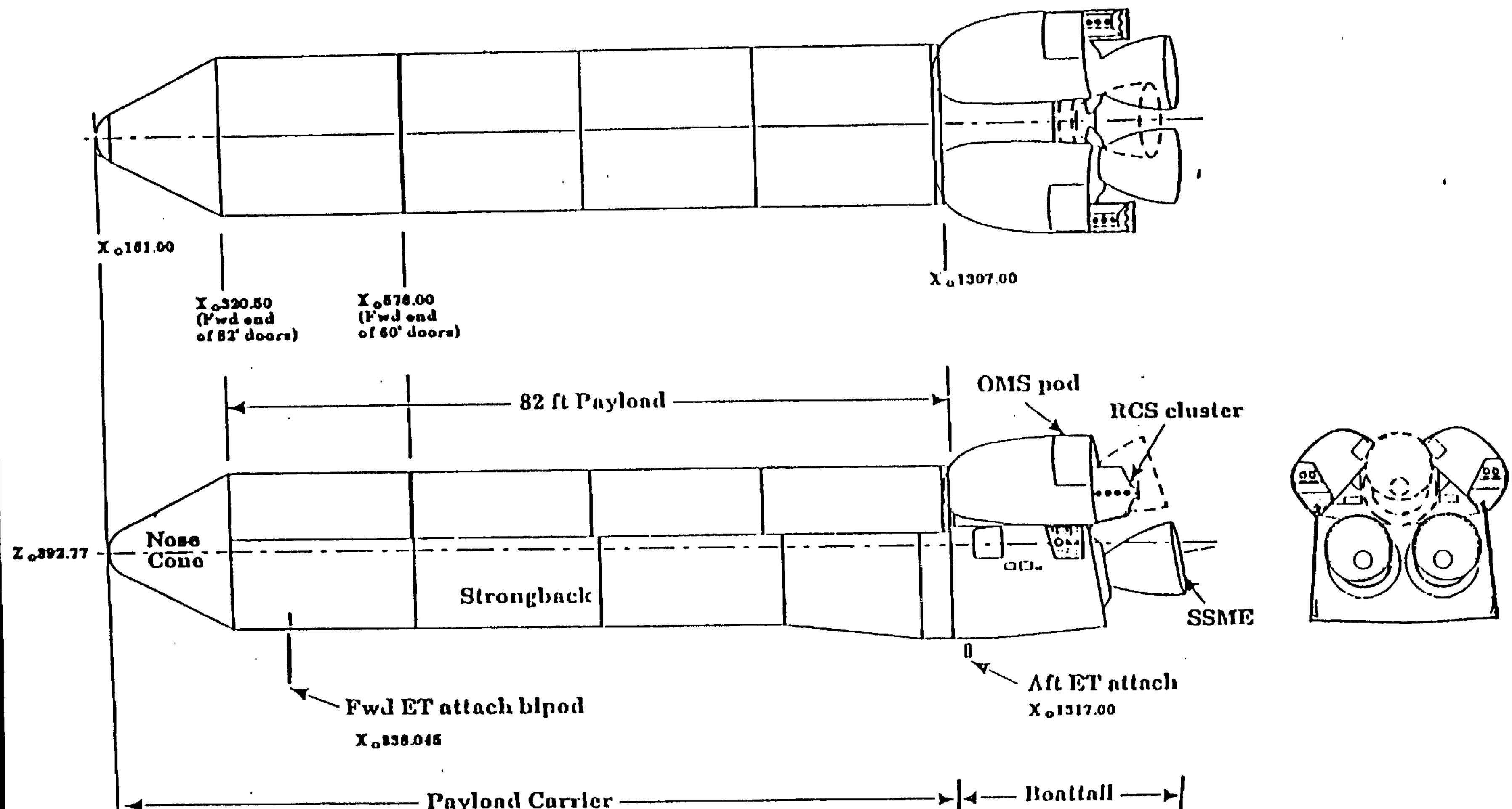
REFERENCE SHUTTLE-C CARGO ELEMENT (CE)

LRB



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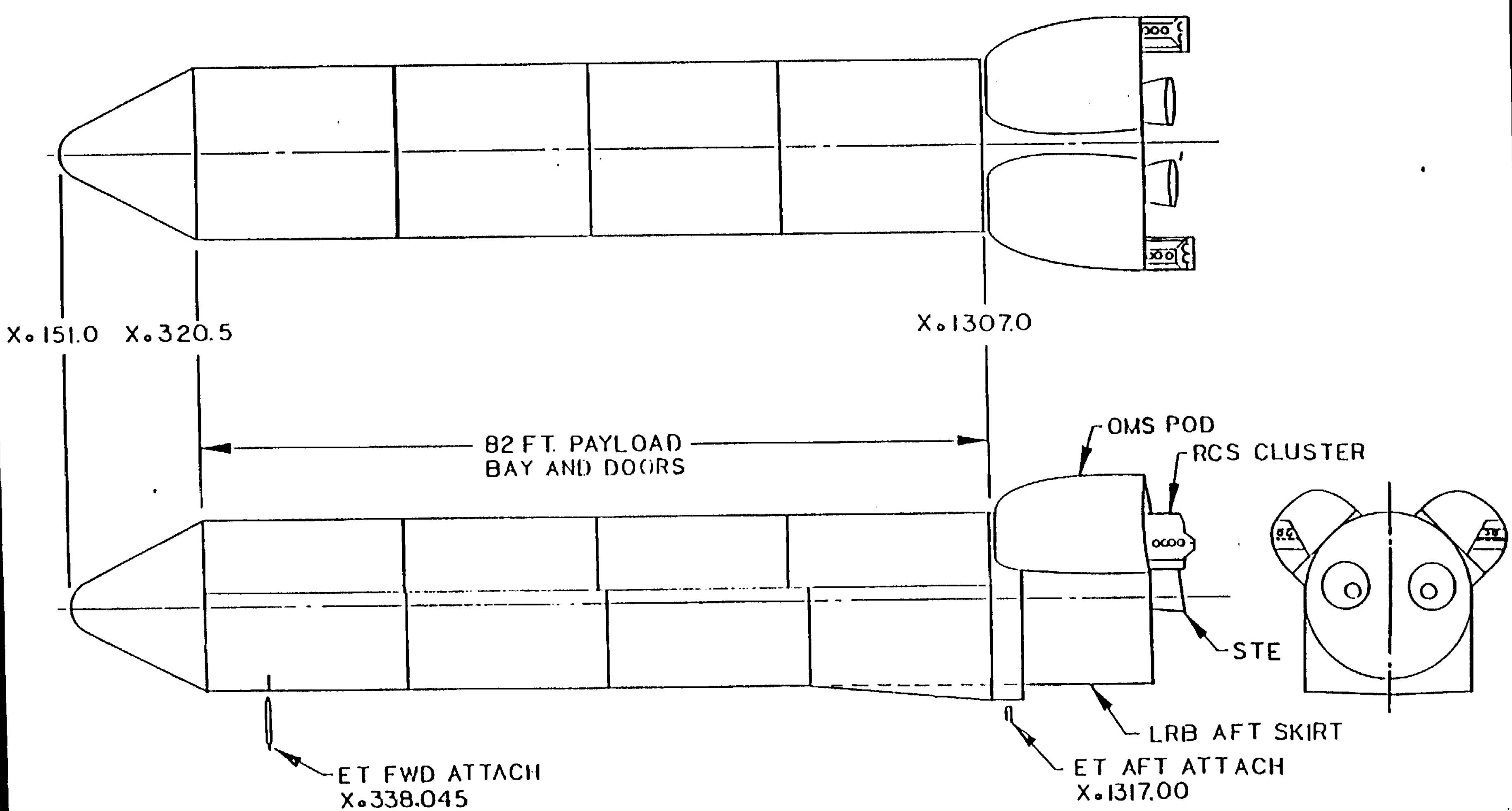
LRB BOATTAIL ON SHUTTLE-C CARGO ELEMENT

LRB



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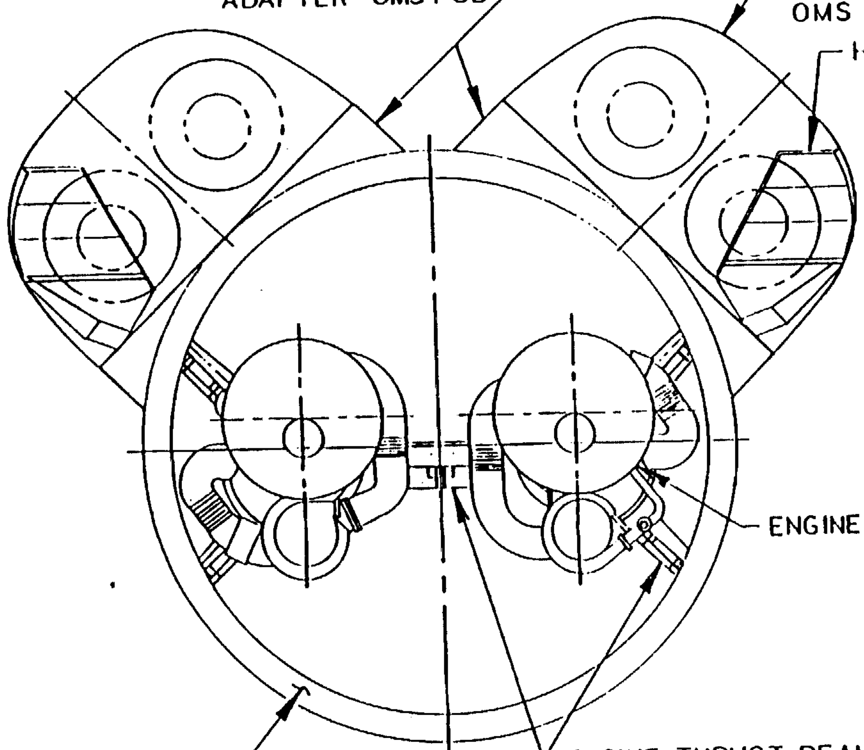
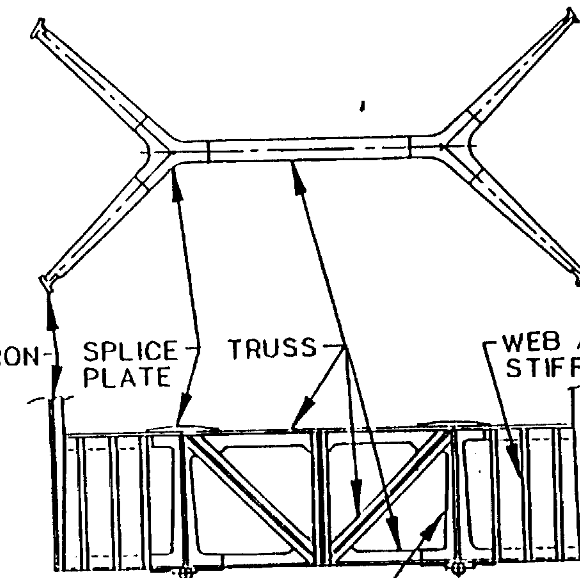
THRUST STRUCTURE FOR 2-STE LRB BOATTAIL

LRB



VIEW LOOKING FWD AT AFT END SHUTTLE C



ENGINE THRUST BEAM
2 ENGINE CONFIGURATION

THE PLS/LRB 2-STE OPTIMIZED THRUST STRUCTURE IS COMMON TO LRB BOATTAIL FOR STS-C

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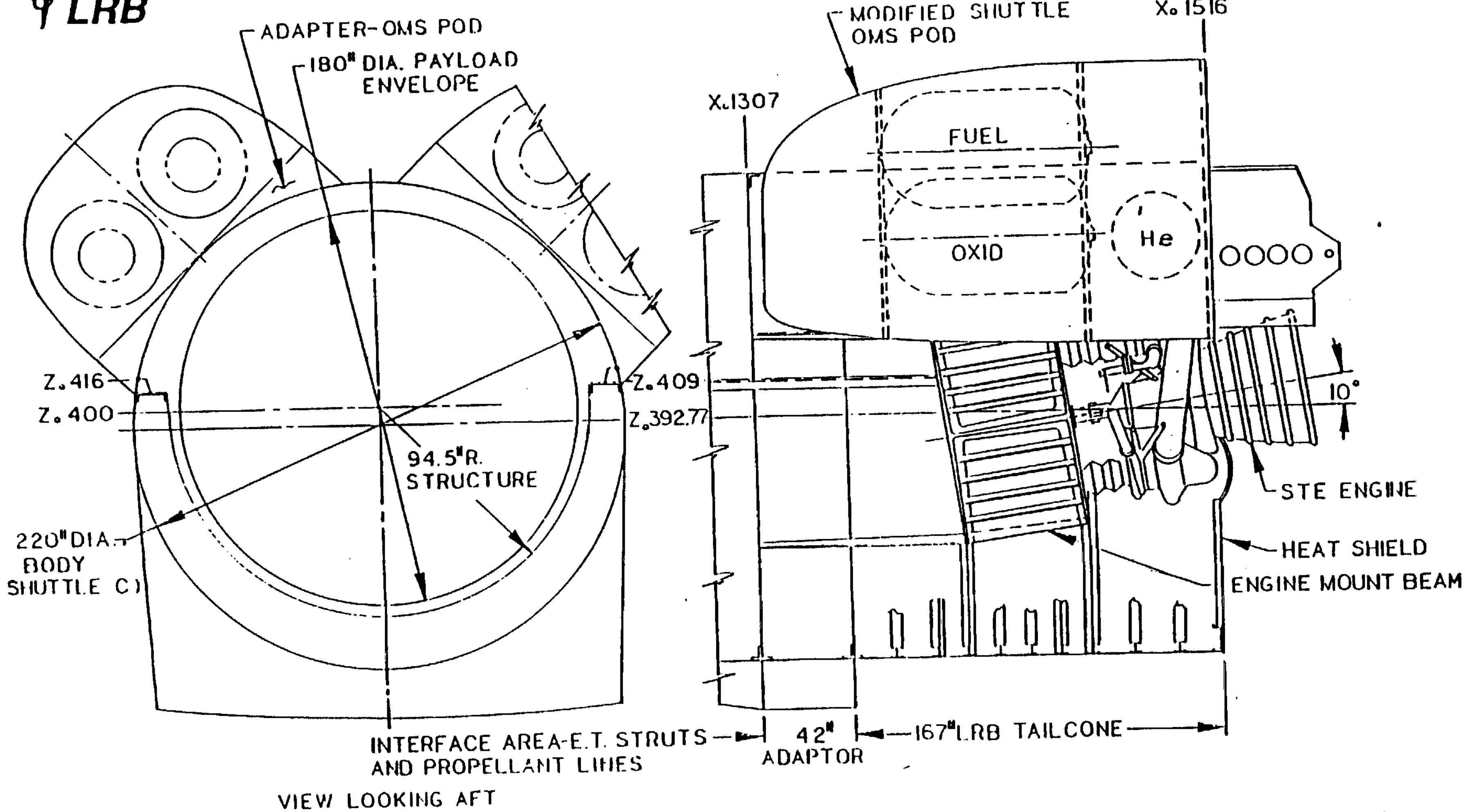
LRB BOATTAIL WITH SHUTTLE-C OMS PODS

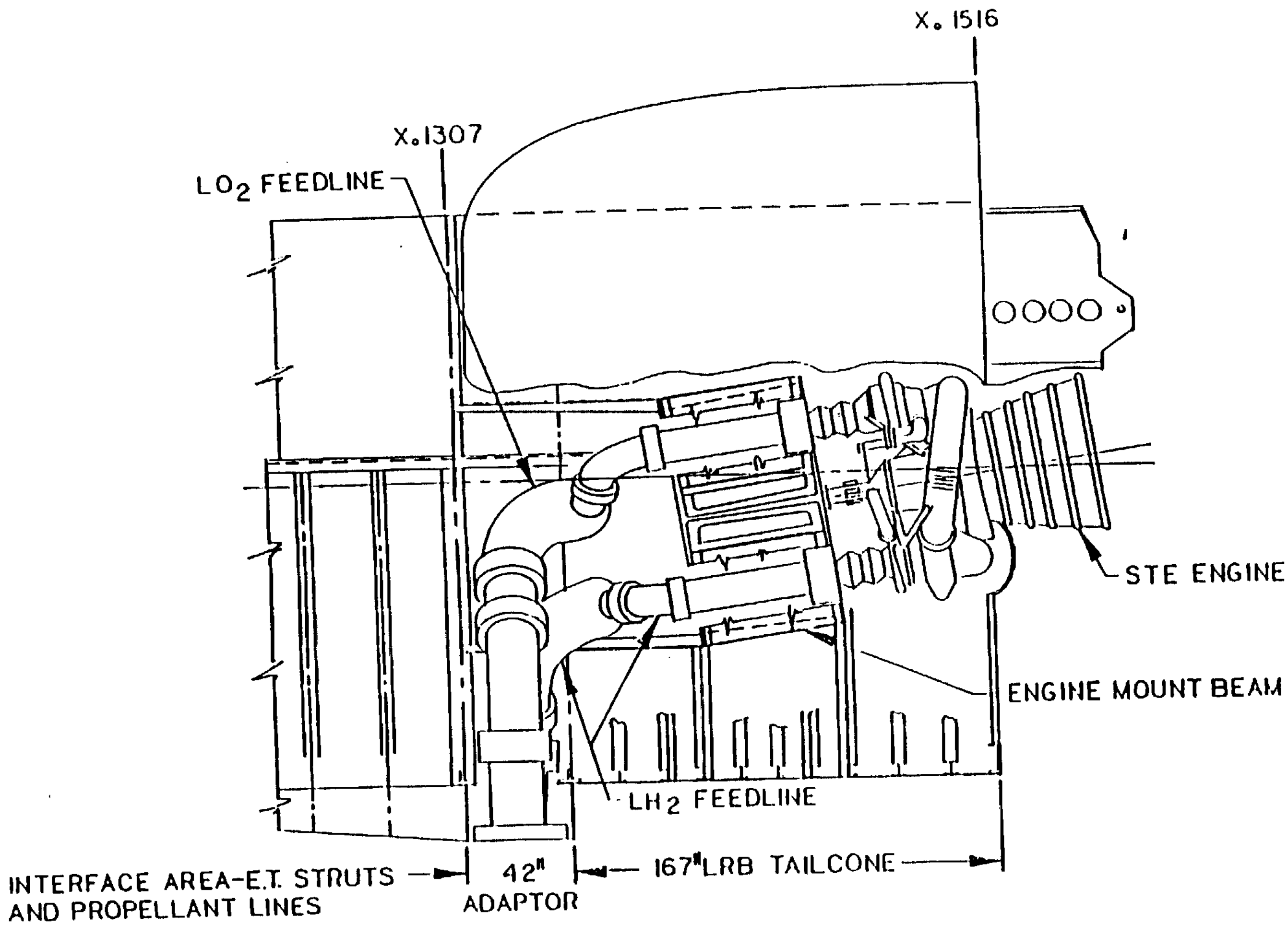
LRB



Interface Of Existing Flat Bottom STS Pod With Curved LRB Boattail Requires An Adapter

PROPELLANT FEED LINES OF STS-C LRB BOATTAIL

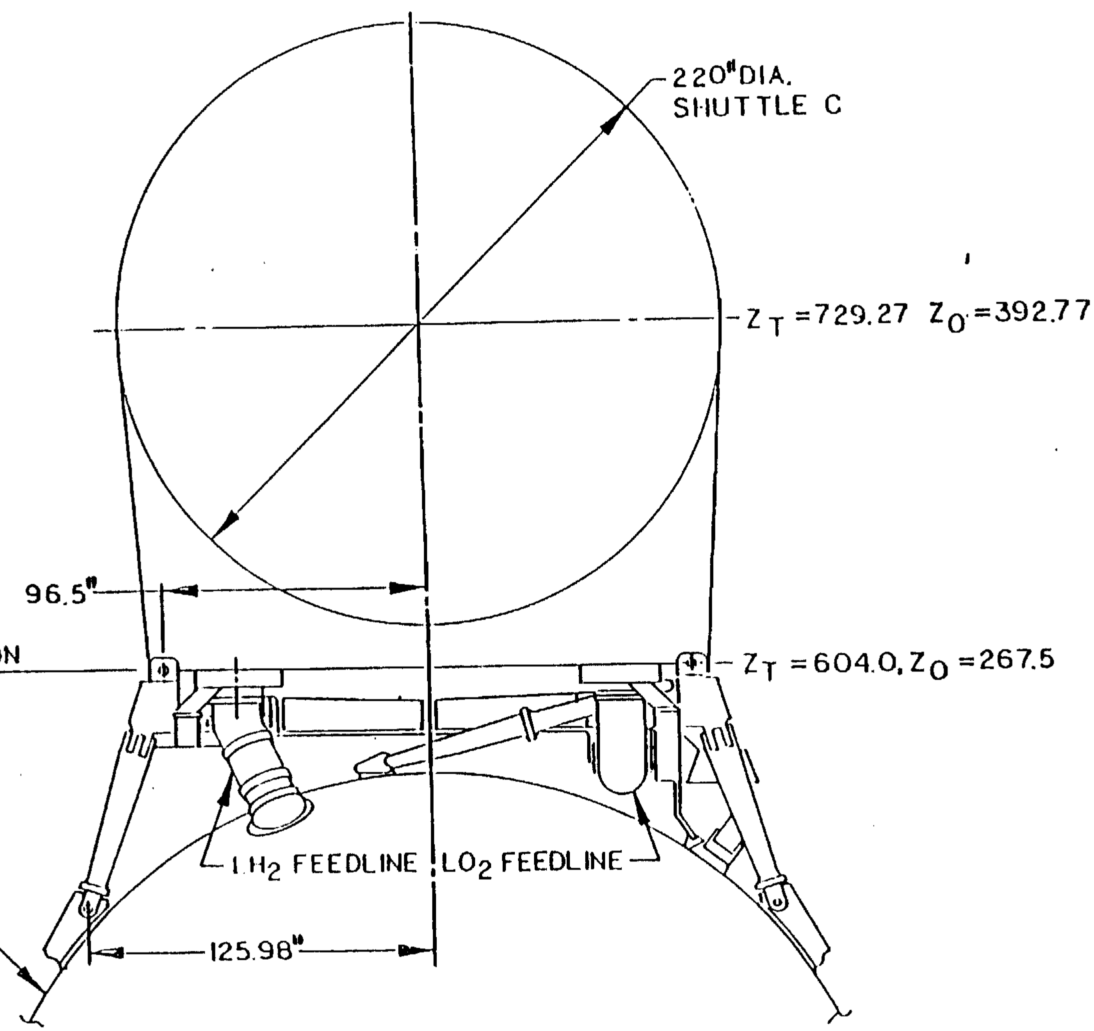
LRB



PROPELLANT LINES INTERFACE OF ET AND LRB BOATTAIL IDENTICAL TO STS

STS ET AFT ATTACH I/F WITH LRB BOATTAIL

LRB



NO CHANGES REQUIRED TO STS ET AFT ATTACH SYSTEM FOR LRB BOATTAIL APPLICATION

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SHUTTLE-C BOATTAIL WEIGHTS COMPARISON

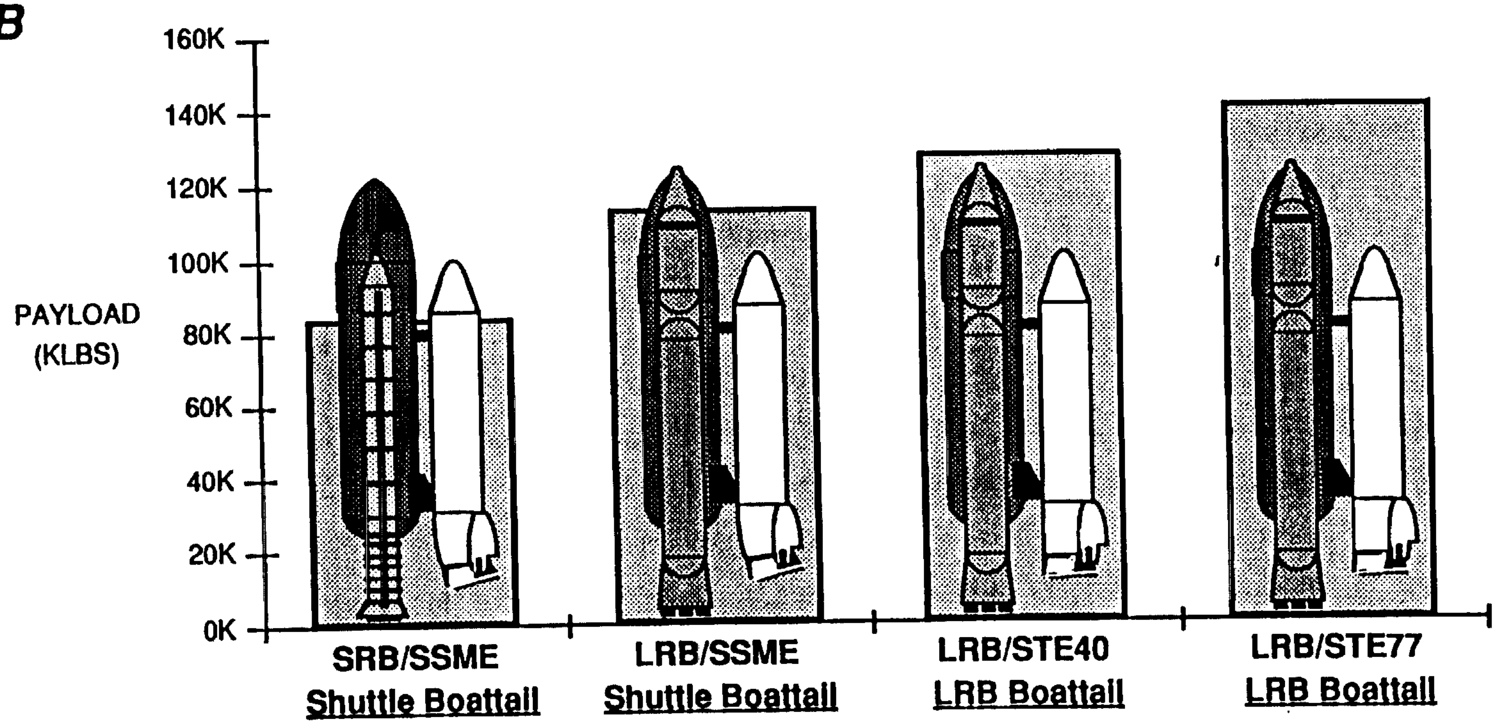
LRB

SUBSYSTEM / ITEM	STS-BOATTAIL / 2-SSME		LRB-BOATTAIL / 2-STE	
DRY WEIGHT		$\boxed{46,115}$		$\boxed{40,896}$
STRUCTURE		14,127		13,181
BASIC SHELL STRUCTURE	6,474		7,355	
THRUST STRUCTURE	3,702		1,905	
OMS/RCS POD	3,031		3,031	
SECONDARY STRUCTURE	920		890	
ENVIRONMENTAL PROTECTION		2,483		2,012
THERMAL PROTECTION	624		341	
BASE HEAT SHIELD	810		622	
THERMAL CONTROL SYSTEM	661		661	
PURGE & VENT SYSTEM	361		361	
DRAIN/HAZARDOUS GAS DETECTION	27		27	
AFT ET ATTACH ASSEMBLY		500		500
MAIN PROPULSION		21,206		18,735
MAIN ENGINES	13,925		13,308	
TVC	2,185		2,203	
PROPELLANT SYSTEM	4,352		2,479	
PNEUMATIC SYSTEM	706		706	
PROPELLANT MNGMNT	38		38	
AUXILLIARY PROPULSION SYSTEM		3,424		3,424
ELECTRICAL PWR & DISTRIB		1,583		1,583
AVIONICS		820		820
HYDRAULIC PWR & DISTRIB		1,330		0
ENVIRONMENTAL CONTROL		642		642

A 5 Klb Lighter And Simpler Structural Design Are Attributes Of An LRB vs An STS Boattail

SHUTTLE-C PERFORMANCE WITH LRB vs SRB

LRB



	SRB/SSME Shuttle Boattail	LRB/SSME Shuttle Boattail	LRB/STE40 LRB Boattail	LRB/STE77 LRB Boattail
Payload (Lbs)	83,140	113,264	127,240	140,224
Percent P/L Increase	---	36 %	53 %	69 %
Boattail Engine Type	2-SSME	2-SSME	2-STE40	2-STE77
Boattail Engine Isp(v) (sec)	452.55	452.55	429.28	441.98
Boattail Dry Weight (Lbs)	46,115	46,115	40,896	42,694
Booster Engine Type	SRB	4-STE20	4-STE20	4-STE20

LRB CONFIGURED STS-C LAUNCH VEHICLES PROVIDE SIGNIFICANTLY HIGHER PAYLOAD CAPABILITY

FINDINGS

CONCEPT DESIGN-LRB BOATTAIL FOR SHUTTLE-C

LRB

- A 69% increase in Shuttle-C payload performance possible with an LRB configured Shuttle-C that includes an LRB boattail Cargo Element (140,224 lb vs 83,140 lb)
- A 5000 lb weight reduction possible by replacing STS with an LRB boattail
- LRB and LRB boattail engine commonality simplifies Shuttle-C design
- A third engine can be integrated in the LRB boattail without major modification
- No problems expected in the integration of the OMS pods and the ET attach assembly based on conceptual layouts
- Cylindrical shaped LRB vs "breadloaf" shaped boattail simplifies design and makes possible Cargo Carrier segments commonality for significant fabrication cost savings

The many advantages of LRB/LRB boattail make it a viable candidate for Shuttle-C

RECOMMENDATIONS
LRB BOATTAIL FOR SHUTTLE-C APPLICATION

LRB

Continuation of Shuttle-C LRB BOATTAIL Study :

- Do feasibility study to develop a conceptual design of an LRB Boattail optimized APS Pod or integration of the APS components within the boattail structure as options to the present large/heavy STS OMS Pod.

- Extend the conceptual design to determine the feasibility/compatibility of integrating the Shuttle-C subsystems in the LRB Boattail that were not addressed in this phase, viz: Avionics; Electrical; ECS; etc.

- Develop a conceptual design of the 3-STE LRB Boattail configuration.

- Conduct performance analyses of following STS-C configurations:

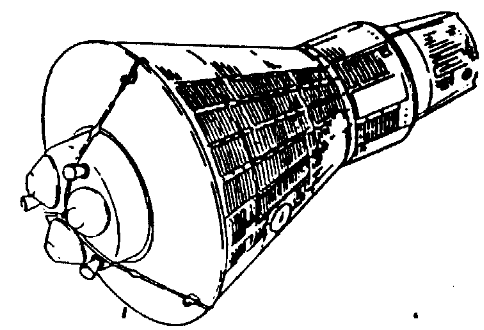
  - Baseline LRBs with 3-STE40 LRB Boattail
  - Baseline LRBs with 3-STE77 LRB Boattail
  - ASRMs with 3-SSME STS Boattail
  - ASRMs with 3-STE77 LRB Boattail
  - ASRMs with 2-SSME STS Boattail

- Cost analysis of STS vs LRB Boattails for Shuttle-C application

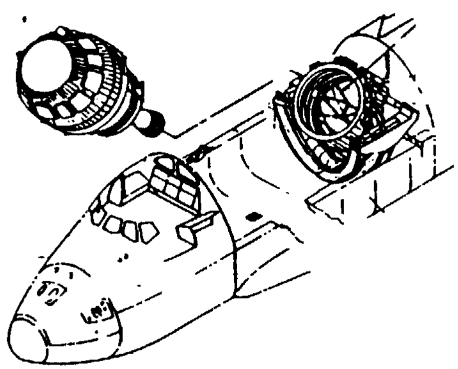
MANNED TRANSPORTATION SYSTEMS

GENERAL DYNAMICS EXPERIENCE

LRB



- ATLAS (RELIABLE) TO MERCURY-ATLAS (MAN-SAFE)
- SHUTTLE-CENTAUR TO TITAN-CENTAUR (FROM MANNED UPPER STAGE TO UNMANNED UPPER STAGE)

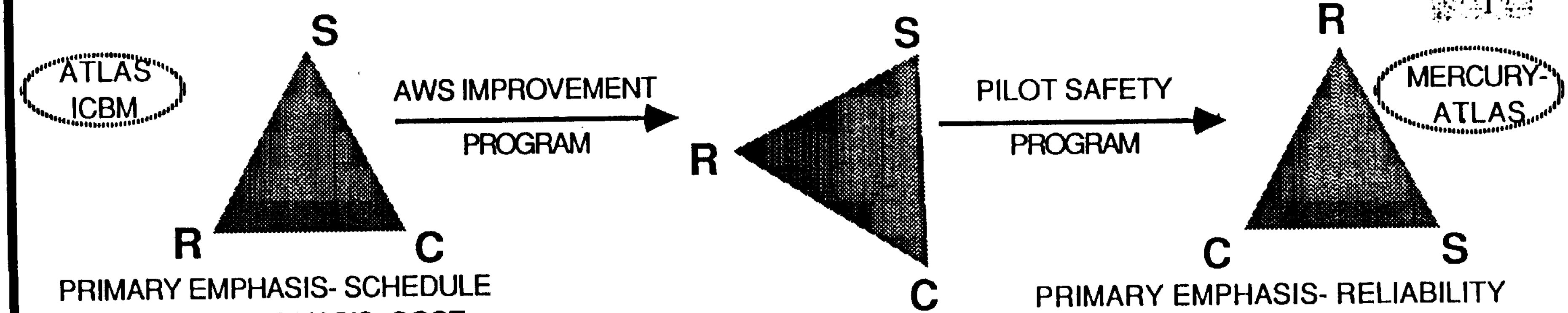


BASIC PRINCIPLES ON MERCURY-ATLAS PROGRAM

- MINIMUM OF NEW DEVELOPMENTS
  - NO CHANGE TO BOOSTER VEHICLE
- PILOT SAFETY PROGRAM
  - ENHANCE SYSTEM RELIABILITY
  - ESCAPE SYSTEM TO FILL GAP BETWEEN 100% RELIABILITY AND BOOSTER RELIABILITY

CHANGE IN PROGRAM MANAGEMENT EMPHASIS

PHASE-IN OF PILOT SAFETY PROGRAM



PRIMARY EMPHASIS- SCHEDULE
SECONDARY EMPHASIS- COST
- RELIABILITY

PRIMARY EMPHASIS- RELIABILITY
SECONDARY EMPHASIS- COST
- SCHEDULE

RESULTS:

1) ENGINE DEMONSTRATED RELIABILITY SUBSTANTIALLY ENHANCED (THROUGH TESTING AND TIGHTENING OF QUALITY CONTROL)

2) ATLAS ICBM RELIABILITY SIGNIFICANTLY INCREASED

3) 100% SUCCESSFUL MANNED FLIGHTS WITH ATLAS

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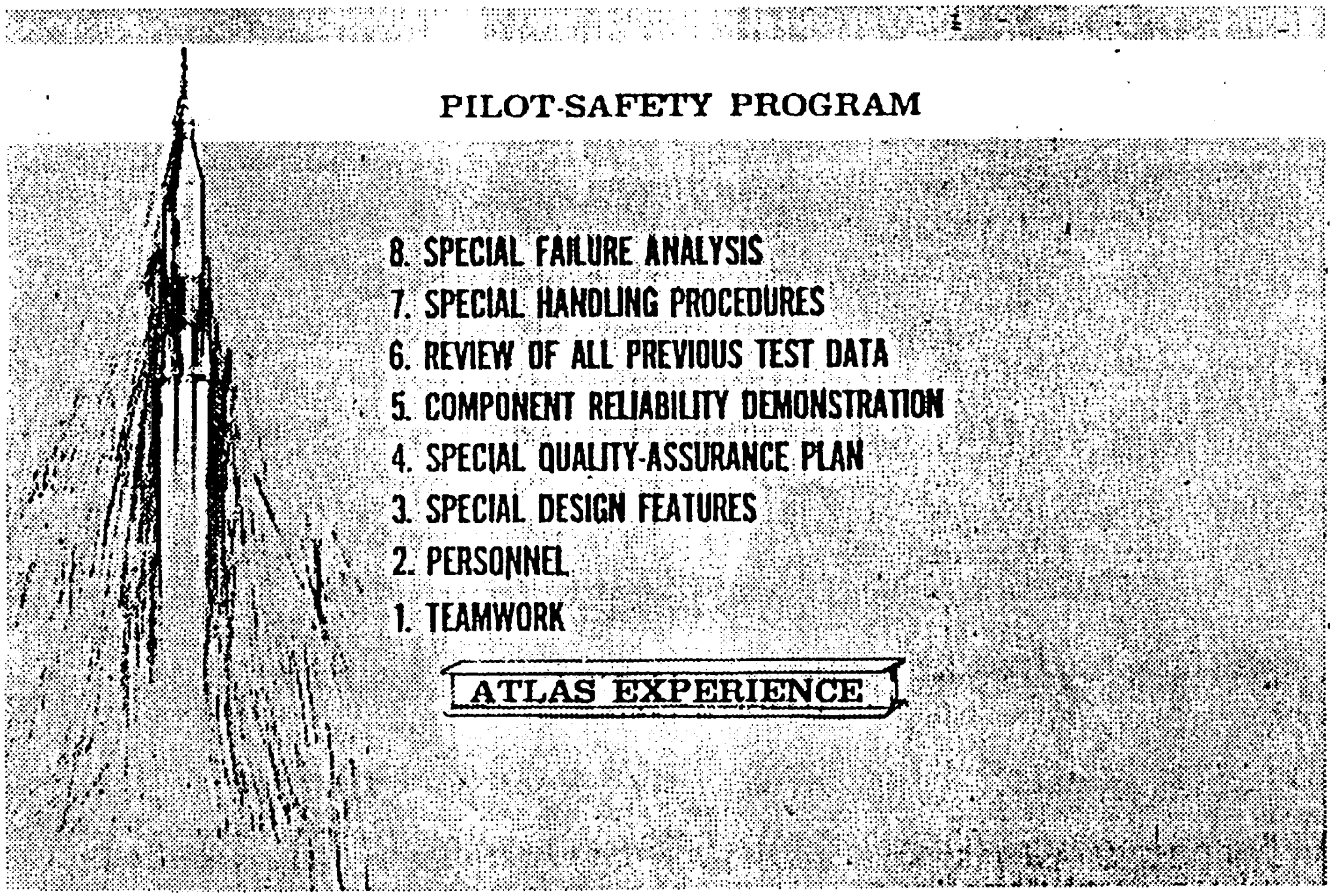
PILOT SAFETY PROGRAM

LRB



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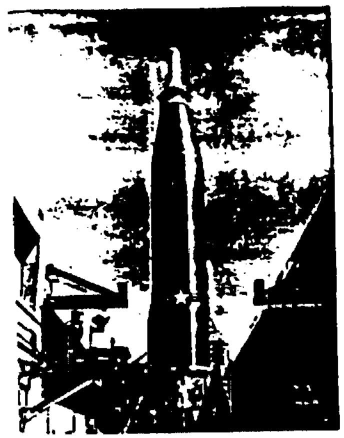
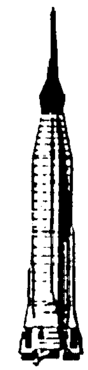
MISSILE TO MAN-SAFE SYSTEM



ATLAS MISSILE



MERCURY-ATLAS

MAJOR CHANGES FROM MISSLE TO MERCURY-ATLAS	DESCRIPTION
• ENHANCE RELIABILITY	• SYSTEM COMPONENTS HAND PICKED TO HAVE CLOSE TO SPEC VALUES
• ADDITION OF ASIS (ABORT SENSING & INSTRUMENTATION SYSTEM)	• NUMBER OF INSTRUMENTATION & LOGIC SYSTEMS TO SENSE HAZARDS, ABNORMAL ENGINE OPERATION, SPURIOUS SIGNAL TO THE RSS ESCAPE SYSTEM
• ESCAPE SYSTEM	• CAPSULE EJECTED TO PROVIDE SAFE ESCAPE FROM IMPENDING FAILURE

GROUNDRULES FOR SHUTTLE-CENTAUR

LRB

- CARGO P/L RULES OR LAUNCH SYSTEM RULES?
  - INITIALLY ONLY MINOR MODS EXPECTED
  - LOTS OF CONFUSION
  - UNIQUE MISSION REQUIREMENTS
- FAIL OPERATIONAL FAIL SAFE
  - PRESSURIZATION, VENTING, AVIONICS, ...
- PROPELLANT DUMP SYSTEM FOR ABORT
- ALMOST AUTONOMOUS SYSTEM
  - ASTRONAUT INITIATE ABORT DUMP SEQUENCE & P/L RELEASE

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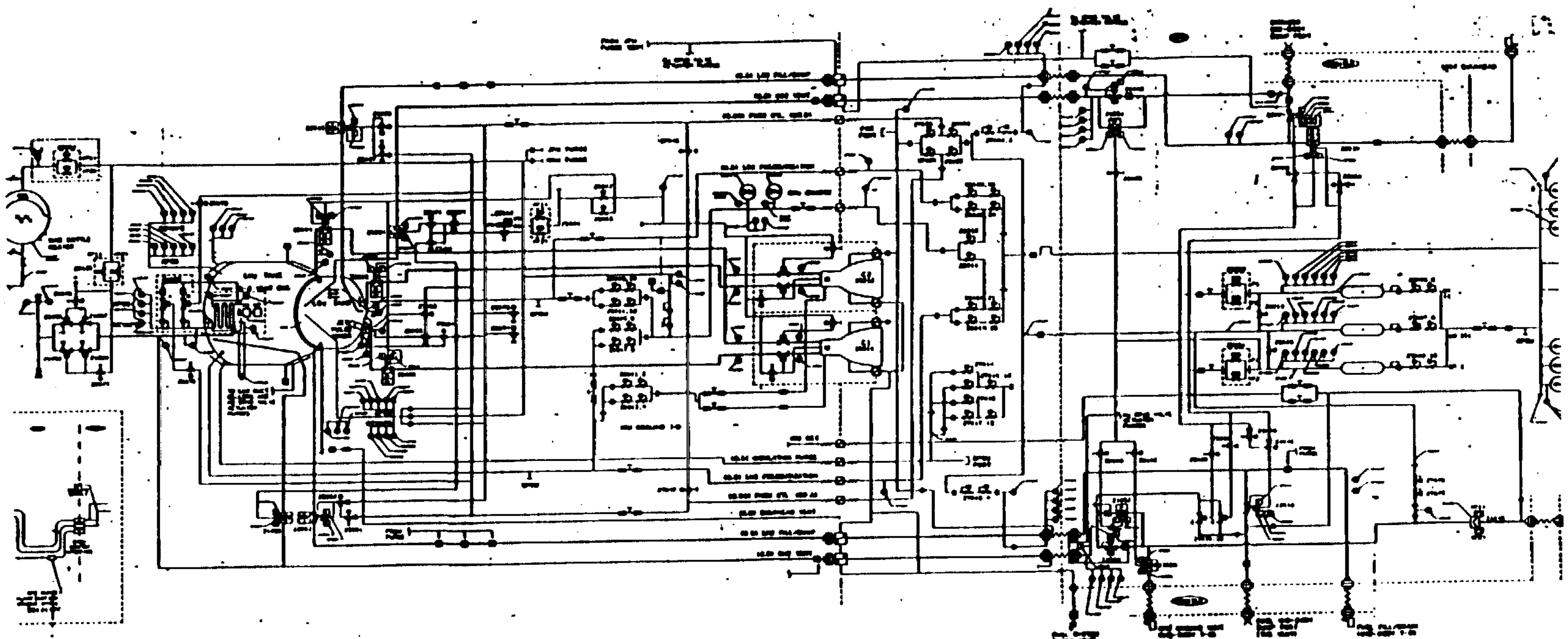
SHUTTLE-CENTAUR FLUIDS SCHEMATIC

LRB



44 Pilot Operated Solenoid Valves
34 Solenoid Valves
29 Check Valves
26 Cryo Valves
5 Pressure Regulators
138

22 Helium Bottles
1 N_2H_4 Bottle

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GENERAL DYNAMICS
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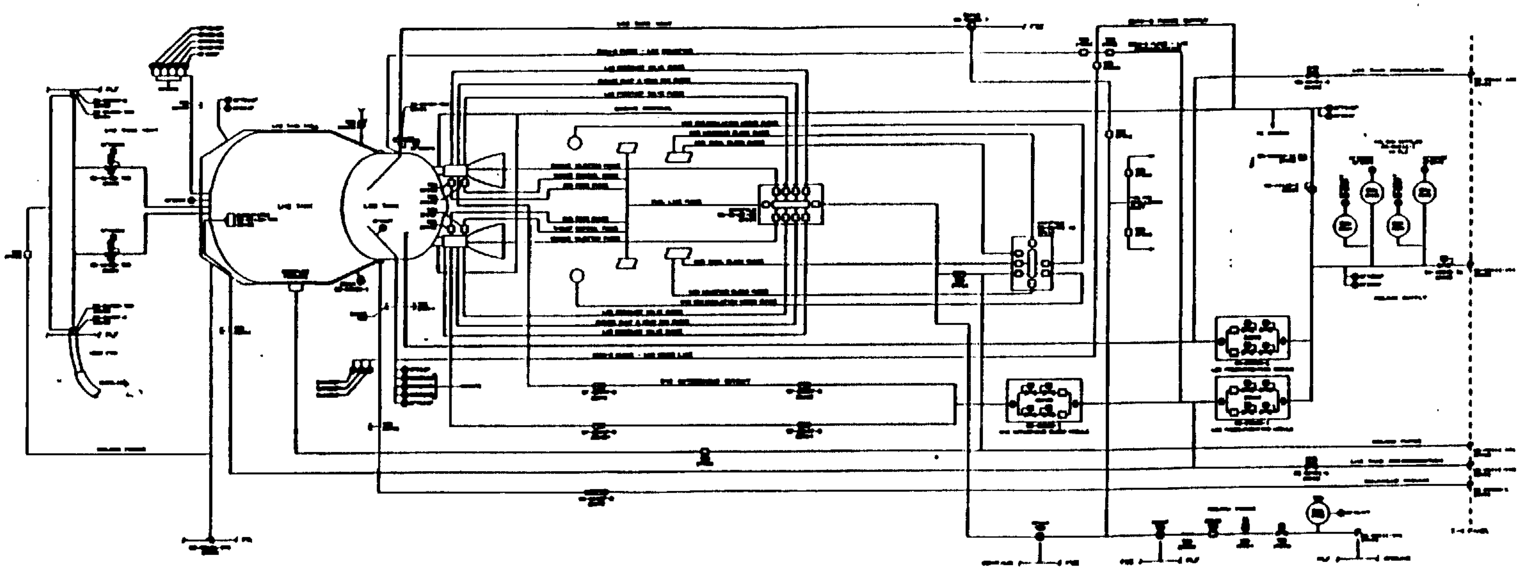
TITAN-CENTAUR FLUIDS SCHEMATIC

LRB



13 PILOT OPERATED SOLENOID VALVES
1 SOLENOID VALVE
6 CHECKVALVES
7 CRYO VALVES
1 PRESSURE REGULATOR
28

5 HELIUM BOTTLES
2 N_2H_4 BOTTLES

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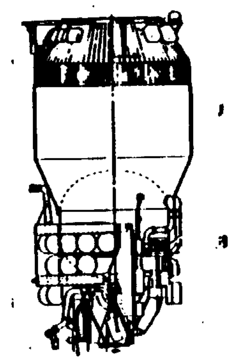
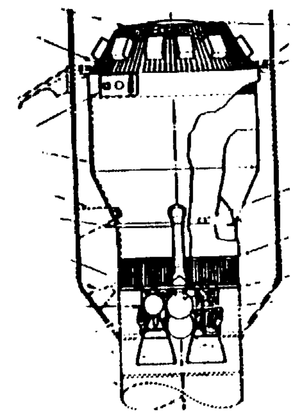
ELV UPPER STAGE TO SHUTTLE UPPER STAGE



SHUTTLE-CENTAUR



TITAN-CENTAUR

MAJOR CHANGE FROM ELV TO SHUTTLE UPPER STAGE	DESCRIPTION
• SAFETY ENHANCEMENT - ADDITION OF DUMP SYSTEM &HDSS - HIGH DEGREE OF REDUNDANCY FAIL-OP FAIL SAFE	• AS SHOWN IN SCHEMATIC, NUMBER OF EXTRA COMPONENTS WERE ADDED TO MAKE SYSTEM DUAL FAILURE TOLERENT, AND START DUMP SEQUENCE IN CASE OF ANY HAZARD
• LOT OF ANALYSIS	• MORE FRACTURE CONTROL AND "WHAT IF" SCENARIO OF A MORE COMPLEX SYSTEM INVESTIGATED
• DISPLAY AND CONTROLS	• SOME CRITICAL DISPLAYS AND DEGREE OF MANUAL CONTROL ON PROPELLANT DUMP PROVIDED
• RIGID QUALITY CONTROL MANAGEMENT REVIEW	• NUMBER OF INTEGRATION PANELS, AND REVIEW COMMITTEES

DESIGN GUIDELINE DOCUMENT

LRB

1. JSC-23211, "GUIDELINES FOR MAN RATING SPACE SYSTEMS" (SEPTEMBER 1988)
2. JSCM-8080, "MANNED SPACECRAFT CRITERIA & STANDARDS" (MARCH 2, 1982 / CHANGE 10)
3. AFSC DH3-2, "DESIGN HANDBOOK, SERIES 3-0, SPACE AND MISSLE SYSTEMS" (MARCH 20, 1969)
4. KHB 1700.7, SPACE TRANSPORTATION SYSTEM PAYLOAD HANDBOOK
5. NHB 1700.7, SAFETY POLICY AND REQUIREMENTS
6. SSP 30000, SPACE STATION PROGRAM DEFINITION AND REQUIREMENTS
7. GDSS-ALS-RPT-89-011, "ALS ADAPTATION FOR MANNED CARGO" (SEPTEMBER 1989)

CLASSIFICATION OF SPACE SYSTEMS (JSC-23211)

LRB

SPACE SYSTEM	MISSION OBJECTIVE	ATTRIBUTES	EXAMPLES
MAN-RATED SYSTEM	MISSION SUCESS & MISSION SAFETY EQUALLY IMPORTANT	• HIGHEST POSSIBLE RELIABILITY • FAIL SAFE OPERATION DESIGNED INTO TOTAL SYSTEM • ESCAPE SYSTEM PROVIDES ULTIMATE BACK-UP	• SPACE STATION
HIGHLY RELIABLE	• MISSION SUCCESS PRIMARY IMPORTANCE • MISSION (OR CREW) SAFETY ENHANCED AS A BY PRODUCT	• HIGHEST POSSIBLE RELIABILITY • FAIL SAFE OPERATION DESIGNED INTO TOTAL SYSTEM	• SHUTTLE - LRB • APOLLO LUNAR LANDER • PRECIOUS CARGO • COMMERCIAL AIRLINES
MAN SAFE	• MISSION (OR CREW) SAFETY HIGHER EMPHASIS THAN MISSION SUCCESS	• RELIABLE • FAIL SAFE OPERATION ONLY OF ESCAPE SYSTEM	• CREW EMERGENCY RETURN • VEHICLE (CERV) - LRB • MERCURY SPACE PROGRAM • FIGHTER AIRCRAFT
REPLACABLE	• NOT VERY HIGH EMPHASIS ON MISSION SAFETY OR MISSION SUCCESS	• EMPHASIS ON COST, SCHEDULE, ETC.	• LOW VALUE CARGO (PROPELLANTS, RE-SUPPLY AND EXPENDABLES)

STRUCTURAL FACTORS OF SAFETY

LRB

LOADING SOURCE / FACTOR	AIRCRAFT	SHUTTLE ET	ATLAS
MECHANICAL LOADS			
YIELD	1.0	1.1	1.0
ULTIMATE	1.5	1.4*	1.25
UNREGULATED PRESSURE			
YIELD	1.0	1.1	1.0
ULTIMATE	1.5	1.4	1.25
BURST	2.0	1.4	1.25
REGULATAED PRESSURE			
YIELD	1.0	1.1	1.0
ULTIMATE	1.5	1.25	1.25
BURST	2.0	1.25	1.25

* F0R WELL DEFINED LOADS, F.S. = 1.25 (MMC-ET-SE25-0, NAS8-303000)

DIFFERENCES BETWEEN MANNED AND UNMANNED SYSTEM

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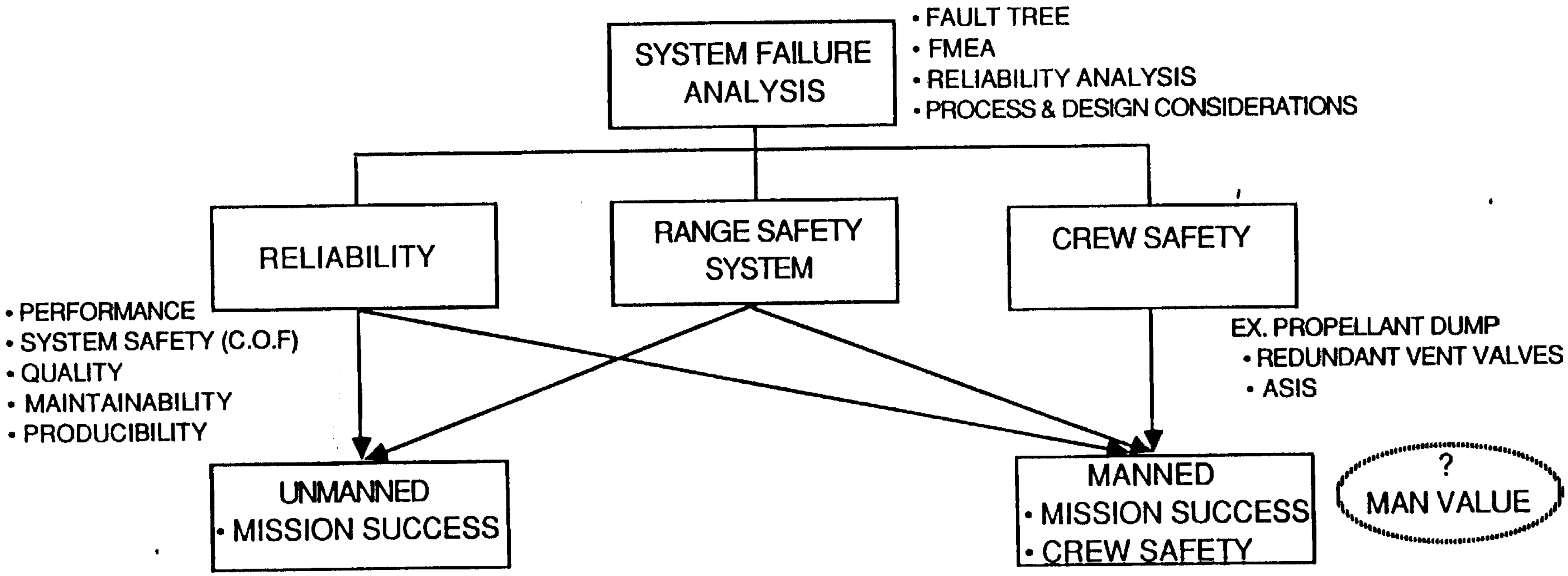

- CONSCIOUS DECISION MADE ON COST EFFECTIVENESS. RELIABILITY DESIRED DEPENDS ON SYSTEM (ATLAS GOAL > .95; ALS GOAL > .985)

- COST EFFECTIVENESS MAY INDIRECTLY INFLUENCE DECISIONS REGARDING CREW-SAFETY (EXAMPLE - SRB, ET H2 VENT DURING ASCENT)
- CREW SAFETY GOAL (APOLLO) > .999
  NASA-TM-89226

ATTRIBUTES OF MANNED AND UNMANNED SPACE SYSTEMS

ATTRIBUTES OF HIGHLY RELIABLE UNMANNED SYSTEM

- PROVEN TECHNOLOGY AND WELL CHARACTERIZED MATERIAL
- FLY THROUGH FAILURES (CRITICAL SYSTEM EXCEPT STRUCTURES, PRESSURE VESSELS & THERMAL PROTECTION SYSTEM SHOULD BE DESIGNED WITH APPROPRIATE DEGREE OF FUNCTIONAL REDUNDANCY)
- ROBUST - A LOT OF MARGIN, SIMPLE DESIGN
- CONTROL OF FAILURE PROPAGATION (HDSS, IHM, LOW CORRELATION OF FAILURE ETC.)
- DEMONSTRATION & VERIFICATION OF RELIABILITY

ADDITIONAL ATTRIBUTES OF HIGHLY RELIABLE MANNED SYSTEM

- CREW DISPLAY AND POSSIBLE PROVISION FOR INTERVENTION (EXTRA REDUNDANCY BY CREW)
- EXTRA REDUNDANCY, DETECTION AND CONTROL WHICH ENHANCES CREW SAFETY AND SAFE ABORT CHANCES

MANNED TRANSPORTATION SYSTEMS

LRB

PRELIMINARY CONCLUSIONS

- A HIGHLY RELIABLE SYSTEM IS ESSENTIAL FOR ALL SPACE SYSTEMS (ENGINE-OUT, PAD-HOLD DOWN, VERIFIED STRUCTURAL MARGIN, ...)

- CREW SAFETY MAY IMPOSE

  - HIGHER MARGINS THAN NEEDED FOR AN OPTIMIZED COST EFFECTIVE UNMANNED SYSTEM
  - REDUNDANCY TO ENHANCE CREW ESCAPE POSSIBILITY (DETERMINED THROUGH ANALYSIS)

- ABORT SENSING AND IMPLEMENTATION SYSTEM IS NEEDED TO FILL THE GAP BETWEEN 100% RELIABILITY AND SYSTEM RELIABILITY

- GENERAL GUIDELINES AVAILABLE. PARTICULAR REQUIREMENTS ARE HIGHLY MISSION SENSITIVE

CONTINUING ACTIVITIES

LRB

- COMPLETE ONGOING CONCEPT DEFINITION & EVALUATION
  - LRB FOR PLS
  - SHUTTLE-C PROPULSION APPLICATION
  - COST DATA FOR SELECTED CONCEPTS
- ET-CORE LAUNCHER SYSTEM
  - TWO LRB'S
  - LRB PROPULSION SECTION TECHNOLOGY FOR ET
  - VARIED PAYLOAD CAPABILITY
- ASSESSMENT OF LRB APPLICATION TO CURRENT PLANS FOR FUTURE LAUNCHERS
- FINAL REPORT & DOCUMENTATION OF CONCEPTS